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Composition and Management of Used Oil Generated in the United States

Franklin Associates Ltd., Prairie Village, KS

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The report summarizes information acquired by the EPA over the period of 1981-1984. Analytical results from over 1000 samples of various types of used oils are presented, and grouped by where the samples came from as well as the recycling method employed. Estimates are also presented concerning the number of facilities generating and processing used oil, as well as the amounts of used oil generated and managed in various ways.

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1984

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PREFACE

This report, prepared for the U.S. Environmental Protection Agency, characterizes used oil generation, management, and composition in the United States in 1983. The information presented in this final report is the result of a comprehensive review and update of a draft report released in December 1983. As part of the review and update, the base year was changed from 1982 to 1983.

This study was carried out to provide the U.S. EPA with the needed background information to develop the most appropriate used oil regulations and to provide a framework for assessing the risks and benefits of alternative regulatory options.

This report was prepared with the help, advice, critical review, and cooperation of several people. William L. Bider, of Franklin Associates, Ltd., directed the study and served as principal author. Staff assistance was provided by Robert G. Hunt, Larry E. Seitter, and Veronica R. Martinez. Michael Petruska, EPA's technical project officer for the study, provided excellent guidance throughout the study period. Several staff members of Temple, Barker, & Sloane, Inc. contributed valuable advice and review for this study, particularly with respect to non-industrial oil generation and flows. Finally, information was contributed by PEDCo Environmental, Inc. on used oil facility characteristics developed through several site visits; and by Energy Resources Company, Inc. on used oil composition developed through a 1983 sampling and analysis program.

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LIST OF ABBREVIATIONS

API - American Petroleum Institute
ATF - automatic transmission fluids
BS&W - bottom sediment and water
Btu - British thermal units
CS - centistokes
DIYer - do-it-yourselfer
EP - extreme pressure
EPA - Environmental Protection Agency
°F - degree Fahrenheit
gal - gallons
g/gal - gram per gallon
hr - hour
IC - independent collector
lb - pound
mg/l - milligrams per liter
mil - million
MJP - major processor
MP - minor processor
ND - not detected
PCBs - polychlorinated biphenyls
PNAs - polynuclear aromatics
ppm - parts per million
PROP - Phillips Re-refining Oil Process
S.I. - surface impoundment
SIC - standard industrial classification
U.O.M.S. - used oil management system
V.O.F.D. - virgin oil fuel dealer
yr - year

Section 1

OVERVIEW OF USED OIL MANAGEMENT AND COMPOSITION

1.1 INTRODUCTION

1.1.1 Background

Over the past decade, there has been widespread and growing interest in used oil issues. Used oil management practices of the late 1960s and early 1970s were criticized as being wasteful of a valuable resource and harmful to the environment. In general, the concerned parties, which included industry, government agencies, and environmentalists, contended that used oils could be handled wisely or unwisely. Wise handling included reuse practices such as re-refining and carefully controlled burning with energy recovery. Unwise handling included such wasteful practices as dumping and even land disposal. Oiling roads with used oil to suppress dust was considered more desirable than pure dumping or land disposal, but less desirable than re-refining or burning as a fuel.

Studies completed in the early 1970s showed that much of the generated used oil in the United States was being managed unwisely (1, 35). Less than one-tenth was re-refined into new lube oil. A larger fraction was burned as fuel, but often without the necessary monitoring to assure that the public was not being exposed to any potentially hazardous substances. More than half of the used oil was being managed in what were generally considered undesirable ways. Over the next decade, additional studies indicated that most unwise management practices continued to occur at significant levels (6, 36-38).

1.1.2 Study Objectives

This study was carried out to characterize used oil management practices in 1983 and to comprehensively summarize used oil composition. A detailed statistical summary of concentration levels is presented for 19 potentially hazardous contaminants found in used oils. Additional chemical and physical criteria that characterize used oil are also presented.* This information includes analytical data describing such oil characteristics as flash point, bottom sediment and water, viscosity, gravity (density), and the concentration of 25 additional contaminants not considered hazardous according to published EPA lists.

The information presented in this report provides a basis for assessing the possible health and environmental implications of various used oil management practices. The data permit quantitative evaluations to be made to determine how widespread potential problems may be. The report also provides concentration data that can be incorporated into pollutant dispersion models to determine the possible human and animal exposure to the hazardous components in used oil as a result of each management practice.

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* Only the detailed summary of hazardous constituents is presented in this overview section. See the other sections and appendices of this report for data on physical characteristics and the concentration of non-hazardous constituents.

1.1.3 Methodology

Two data bases were developed as part of this study: one characterizing used oil flow through the management system and the other characterizing used oil composition. This task was accomplished by a thorough literature search, telephone inverviews with government and industry, and approximately 25 site visits to facilities involved in used oil management. Much of the information regarding the flow of used oil is undocumented because of the unstructured nature of the used oil management system. Current (1983) Federal regulations do not require participants in the used oil industry to report their collection procedures or reuse practices. Some states have implemented programs to monitor used oil transactions, but most of these programs are still in the early stages of development. Thus, much of the collection, reprocessing, and reuse of waste oils in this country is not documented. For this reason, it was often necessary to make reasonable "best estimates" of used oil flows based upon reported conditions.

The approach to quantifying the flow of oil through the used oil management system is based on the flow of new oil through the system. It begins with current (1983) sales and follows these oils through the system until they are ultimately reused, consumed, or disposed of in some manner, including uncontrolled dumping.* (Old oils that are no longer sold, such as transformer oils containing PCBs, are omitted from this analysis.)†

---

* Appendix C provides a thorough description of the methodology and assumptions used to develop used oil flows.

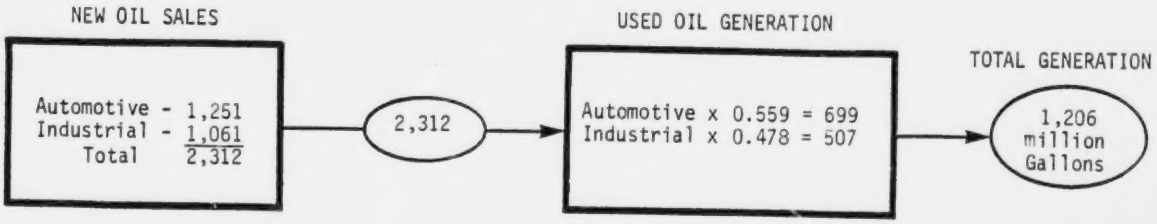
† It has been estimated that at least 50 million gallons of PCB-containing oil is disposed of annually at designated facilities that are supposedly outside the used oil management system described in this report.

Other oily wastes that are omitted from this analysis because they comprise part of a different system are refinery tank bottoms, oil spill debris, and certain industrial process residues. These materials are occasionally added to oils that are part of the system; however, this practice is entirely undocumented and random.

The approach used to summarize waste oil composition is based upon the development of a series of fairly simple statistical parameters that characterize over one thousand used oil samples with respect to the concentrations of 19 potentially hazardous constituents. The statistical summaries include the determination of the mean, median, 75th and 90th percentiles, and range of concentrations for each hazardous constituent.

1.2 USED OIL GENERATION

The total volume of used oil generated in the United States depends on the quantity of new oil sold into each application (i.e., sales by specific automotive and industrial oil types). These sales data, along with generation rates for each application, were used to develop the volume of total generated used oil. A summary of automotive and industrial oil sales and generation is shown in Figure 1.


NEW OIL SALES
Automotive - 1,251
Industrial - 1,061
Total 2,312
2,312
USED OIL GENERATION
Automotive x 0.559 = 699
Industrial x 0.478 = 507
TOTAL GENERATION
1,206 million Gallons

Note: All values in million gallons.

Figure 1. Used oil generation in 1983.

Source: See Appendix C for flow description methodology.

Only 1.2 billion gallons of used oil were generated from sales of over 2.3 billion gallons in 1983. Automotive oil generation was substantially higher than industrial oil generation due to higher sales and a higher average generation factor (699 million gallons compared to 507 million gallons of industrial used oil). Nearly 56 percent of automotive oils is assumed to be generated compared to about 48 percent of industrial oils and automotive oil sales were about 18 percent higher. The difference in generation is based upon the observed differences for specific types of automotive and industrial oils (see Table 13 in Section 3). Generation rates for various oils depend upon losses which occur during use or handling as a result of leakage, spillage, combustion, disposal with equipment,* and incorporation into a finished product such as paint, putties, rubber, etc.

1.3 USED OIL MANAGEMENT

The used oil management system (U.O.M.S.) is comprised of companies which collect, process, and sell used oil into several markets. There are three basic types of companies involved in this industry: (1) independent collectors, who only collect and sell used oil; (2) processors, who collect, process, and sell an improved product oil; and (3) re-refiners, who collect, process, and sell a re-refined lube base stock. Many variations exist for each basic type of company.

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* Includes the disposal of electrical, cooling, and hydraulic oils with decommissioned equipment containing these oils.

For this analysis, nine specific company types were selected to model the used oil management system. Table 1 lists these "typical" facility types and shows their numbers, sizes, and total annual facility throughput. Only one type of independent collector was selected to model that system. Six types of minor and major processors were identified based upon the degree and type of processing, while two types of re-refiners were selected. The total number of facilities represented by these models, excluding independent collectors, is 253. This total number is believed to be fairly accurate for 1983. However, the number of facilities of each specific type is somewhat uncertain because the total population of 253 was disaggregated to fit the relatively small number of typical options shown in Table 1.

One important fact is that only 13 of the 253 processing companies are involved in re-refining. Although typical re-refiners are larger than typical processors, re-refiners handle less than 15 percent of all oil which enters the used oil management system.

Figure 2 shows the flow of used oil from the point of generation through the management system to reuse or disposal. Also included is a description of the reuse practices for generated oil which does not flow through the systems. This oil is reused or disposed of directly by the generators. Only 55 percent (669.1 million gallons) of all generated used oil enters into the used oil management system. The remainder is reused, and a lubricant or fuel, dumped, or disposed of by the generators, primarily DIYers.

The flow in Figure 2 shows that all types of collectors and processors market used oil to all end-use markets. However, the relative importance of a given market to a specific facility type varies. For

Table 1

TYPICAL COMPANIES INVOLVED IN USED OIL MANAGEMENT

Selected typical model facilities*	Estimated number of facilities†	Typical facility size (1,000 gal/yr)	Total annual volume for model type‡ (10^6 gal)
Independent Collectors	500 to 1,000	500	167.3
Minor Processors			
MP-1	50	750	34.3
MP-2	65	1,500	88.4
Major Processors			
MJP-1	60	2,500	139.4
MJP-2	20	2,500	46.3
MJP-3	20	2,500	46.3
MJP-4	25	7,500	174.7
Subtotal - Processing	240		529.4
Re-refiners			
Vacuum Distillation	10	8,000	75
Acid-Clay	3	3,500	10
Subtotal - Re-refining	13		85
Total (excluding independent collectors)	253		614.4**

* Brief facility descriptions are listed below for collectors and processors.

- Independent Collector - collects and stores only
- MP-1 - collects, stores, and settles
- MP-2 - collects, stores, and settles using heat treatment
- MJP-1 - collects, stores, processes using heat treatment, emulsion breaking, centrifugation, and filtration
- MJP-2 - Same as MJP-1, except other waste materials (e.g., septic wastes) are handled in addition to used oil
- MJP-3 - Same as MJP-1, except blending with virgin fuel oils occurs on-site.
- MJP-4 - Same as MJP-1, except other hazardous wastes (e.g., solvents) are handled in addition to used oil which is typically mixed with the oil

† It was assumed that all companies fit into one of the selected models. Mid-1983 estimates are shown.

‡ Flow estimates were not calculated by simply multiplying columns two and three. See Appendix C for a description of the development of these 1983 used oil flows.

** This volume is 9.2 million gallons higher than the total amount of used oil entering the system because some oil is transferred from minor processors to major processors or re-refiners.

Source: Franklin Associates, Ltd.

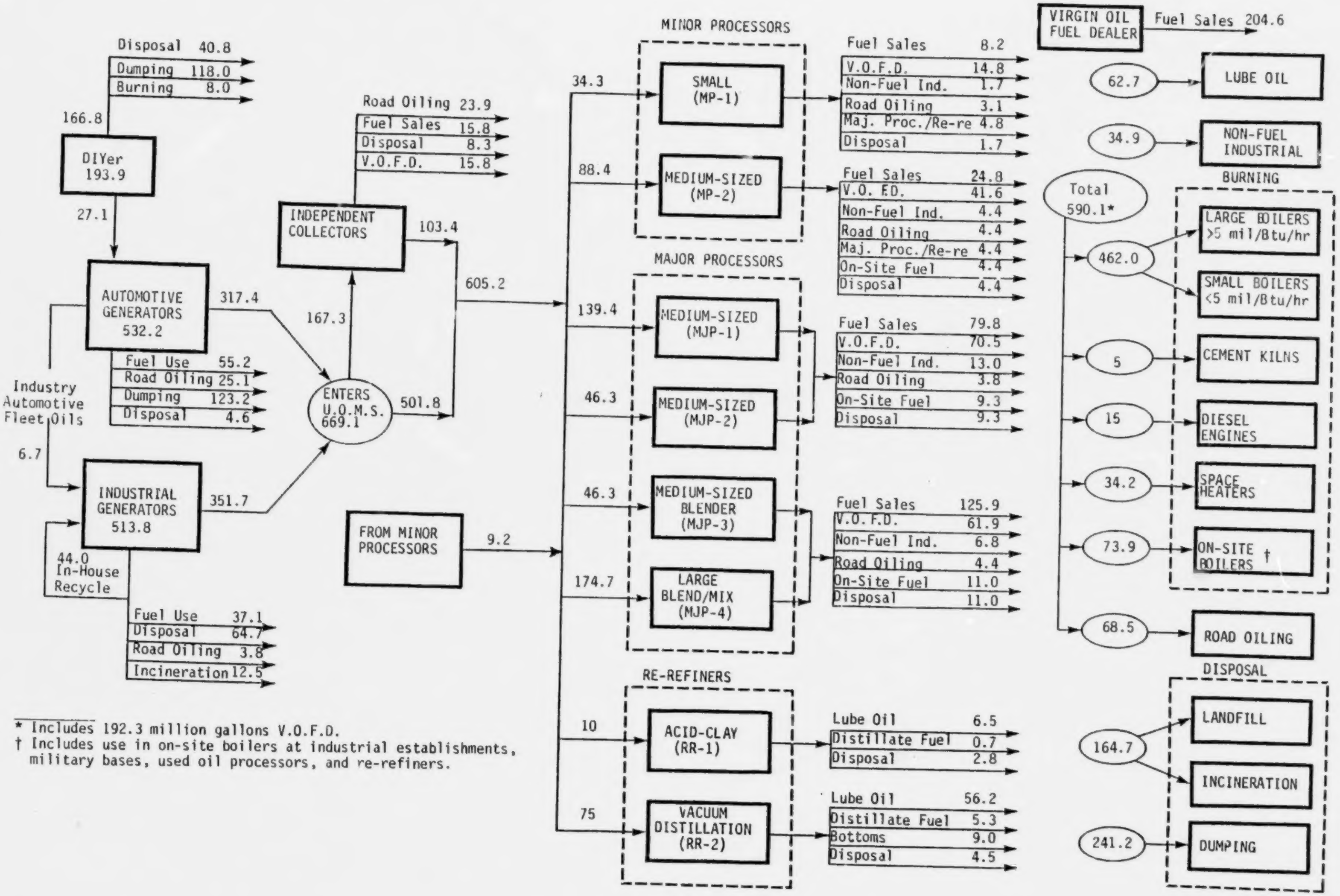
DIYer 193.9
166.8
Disposal 40.8
Dumping 118.0
Burning 8.0
27.1
AUTOMOTIVE GENERATORS 532.2
317.4
Fuel Use 55.2
Road Oiling 25.1
Dumping 123.2
Disposal 4.6
Industry Automotive Fleet Oils
6.7
INDUSTRIAL GENERATORS 513.8
351.7
44.0 In-House Recycle
Fuel Use 37.1
Disposal 64.7
Road Oiling 3.8
Incineration 12.5
ENTERS U.O.M.S. 669.1
167.3
501.8
INDEPENDENT COLLECTORS
103.4
Road Oiling 23.9
Fuel Sales 15.8
Disposal 8.3
V.O.F.D. 15.8
605.2
FROM MINOR PROCESSORS
9.2
MINOR PROCESSORS
34.3
SMALL (MP-1)
88.4
MEDIUM-SIZED (MP-2)
MAJOR PROCESSORS
139.4
MEDIUM-SIZED (MJP-1)
46.3
MEDIUM-SIZED (MJP-2)
46.3
MEDIUM-SIZED BLENDER (MJP-3)
174.7
LARGE BLEND/MIX (MJP-4)
RE-REFINERS
10
ACID-CLAY (RR-1)
75
VACUUM DISTILLATION (RR-2)
Fuel Sales 8.2
V.O.F.D. 14.8
Non-Fuel Ind. 1.7
Road Oiling 3.1
Maj. Proc./Re-re 4.8
Disposal 1.7
Fuel Sales 24.8
V.O. F.D. 41.6
Non-Fuel Ind. 4.4
Road Oiling 4.4
Maj. Proc./Re-re 4.4
On-Site Fuel 4.4
Disposal 4.4
Fuel Sales 79.8
V.O.F.D. 70.5
Non-Fuel Ind. 13.0
Road Oiling 3.8
On-Site Fuel 9.3
Disposal 9.3
Fuel Sales 125.9
V.O.F.D. 61.9
Non-Fuel Ind. 6.8
Road Oiling 4.4
On-Site Fuel 11.0
Disposal 11.0
Lube Oil 6.5
Distillate Fuel 0.7
Disposal 2.8
Lube Oil 56.2
Distillate Fuel 5.3
Bottoms 9.0
Disposal 4.5
VIRGIN OIL FUEL DEALER
Fuel Sales 204.6
62.7
LUBE OIL
34.9
NON-FUEL INDUSTRIAL
Total 590.1*
BURNING
462.0
LARGE BOILERS >5 mil/Btu/hr
SMALL BOILERS <5 mil/Btu/hr
5
CEMENT KILNS
15
DIESEL ENGINES
34.2
SPACE HEATERS
73.9
ON-SITE BOILERS †
68.5
ROAD OILING
DISPOSAL
164.7
LANDFILL
INCINERATION
241.2
DUMPING

Figure 2. Used oil flow description in the United States - 1983 (millions of gallons).

Source: See Appendix C for description of flow methodology.

---

* Includes 192.3 million gallons V.O.F.D.

† Includes use in on-site boilers at industrial establishments, military bases, used oil processors, and re-refiners.

example, on the average, independent collectors sell about 14 percent of their used oil for road oiling compared to only 2 percent for major processors, 5 percent for large minor processors, and 10 percent for small minor processors.

The fuel oil market clearly dominates with respect to end-use applications. About 590 million gallons (nearly 50 percent of all used oil generated) were burned as a fuel in 1983. About 73 percent (490 million gallons) of the oil entering the U.O.M.S. was burned as fuel. Probably about half of the burned oil was blended with virgin fuel oil before being burned. Used oil is burned in many types and sizes of industrial, commercial, residential and institutional boilers, and small space heaters. The industrial market is clearly the largest, but all burner types are significant users, at least in some regions of the country.

Similar amounts of used oil were re-refined and applied to roads for dust control in 1983. About 85 million gallons were received by re-refiners and nearly 74 million gallons were used as road oil. Less than 50 million gallons of the used oil entering the U.O.M.S. were used for road oiling. The remaining activity was carried out by generators. As more and more states discourage and prohibit road oiling, this commercial practice will probably decrease even without federal regulation. Only about 70 percent of the oil received by re-refiners becomes new lube stock. Most of the remainder is recovered as a lighter distillate fuel or lost during processing.

Figure 2 shows that 34.9 million gallons of used oils are marketed for non-fuel industrial purposes. The major applications in this category include flotation oils, asphalt extenders, and form oils.

More used oil is lost to disposal than consumed for all purposes if burning is omitted. In 1983, over 400 million gallons were believed lost via the three disposal mechanisms including landfilling, incineration, and dumping. Nearly 50 percent more oil is dumped as is disposed of by landfilling and incineration combined. Most of the dumped oil is automotive oil generated by DIYers and large off-road equipment operators such as farmers, mining and construction companies, and the military.

1.4 USED OIL COMPOSITION

During service, the additives in lubricating oils are chemically changed or consumed, and the oil itself becomes contaminated from both internal and external sources. The primary source of internal contamination is the breakdown of the additive package and subsequent interaction among its chemical components. These components may be oxidized during combustion, forming corrosive acids. Examples of general sources of contamination include soot and lead compounds from engine blowby;* dirt and dust; metal particles from engine wear; rust; gasoline from incomplete combustion; and water from blowby vapor. In addition to these sources of contamination which are directly related to use, another important external source is mixing or dumping of materials into used oil through carelessness or ignorance. Contamination by metals and PNAs seems primarily related to the nature of the oil and its additives and actual use, whereas contamination with chlorinated solvents and PCBs seems primarily related to poor management practices.

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* Engine blowby is material which leaks from the engine combustion chamber into the crankcase where the oil resides.

Table 2 summarizes used oil contamination with respect to 19 specific constituents, 17 of which are included on EPA's published list of hazardous constituents.* The results are statistically summarized according to percent detection, mean, median, 75th and 90th percentile concentrations, and range. The results show that the means are greatly distorted by a few very high concentrations. For every contaminant, the mean is much higher than the median (50th percentile), which in this case is a better indicator of typical concentrations.†

Extremely high levels of contamination which occur in one, or perhaps a few samples, can also distort the statistical summary of composition. A comparison of contaminant concentrations at the 90th percentile and upper end of the ranges illustrates this phenomenon. In virtually all cases, the highest measured value is many times greater than the 90th percentile concentration because one or more very high concentrations have resulted through unusual circumstances or possibly adulteration of the oil by a generator or collector. Although these high levels of contamination can occur in used oil, they are atypical.

The following subsections summarize used oil contamination for each major group of contaminants. Used oil contamination is summarized by source, stage of processing, and end-use in Sections 3, 4, and 5.

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* Part 261 - Identification and Listing of Hazardous Waste. Appendix VIII - Hazardous Constituents. Code of Federal Regulation (40 CFR), July 1, 1981

† In subsequent sections of this report which examine the contamination of specific oil types, an alternative method of determining mean is presented. In that analysis, the mean was calculated including undetected levels assuming that the concentration of undetected contaminants is equal to the detection level.

Table 2

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN WASTE OIL*

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	537	135	25	17.26	5	5	18	<0.01	100
Barium	752	675	89	131.92	48	120	251	0	3,906
Cadmium	744	271	36	3.11	3	8	10	0	57
Chromium	756	592	78	27.97	6.5	12	35	0	690
Lead	835	760	91	664.5	240	740	1,200	0	21,700
Zinc	810	799	98	580.28	480	872	1,130	<0.5	8,610
Chlorinated Solvents									
Dichlorodifluoromethane	87	51	58	373.27	20	160	640	<1	2,200
Trichlorotrifluoroethane	28	17	60	62,935.88	160	1,300	100,000	<20	550,000
1,1,1-Trichloroethane	616	388	62	2,800.41	200	1,300	3,500	<1	110,000
Trichloroethylene	608	259	42	1,387.63	100	200	800	<1	40,000
Tetrachloroethylene	599	352	58	1,420.89	106	600	1,600	<1	32,000
Total Chlorine	590	568	96	4,995	1,600	4,000	9,500	40	86,700
Other Organics									
Benzene	236	118	50	961.2	20	110	300	<1	55,000
Toluene	242	198	81	2,200.48	380	1,400	4,500	<1	55,000
Xylenes	235	194	82	3,385.54	550	1,400	3,200	<1	139,000
Benzo(a)anthracene	27	20	74	71.3	12	30	40	<5	660
Benzo(a)pyrene	65	38	58	24.55	10	12	16	<1	405
Naphthalene	25	25	100	475.2	330	560	800	110	1,400
PCBs	753	142	18	108.51	5	15	50	0	3,800

* Results determined for the analyses of 1,071 used oil samples.
† Calculated for detected concentrations only.
‡ For the purposes of determining mean and percentile concentrations, undetected levels were assumed to be equal to the detection limit.

Source: Appendix A data.

1.4.1 Metals Concentrations in Used Oils

Trace metals of concern enter used oil from several different sources. Most notable is lead, which is primarily attributable to piston blowby in engines using leaded gasoline. Lead may also be a minor component of some antiwear/extreme pressure additives. Barium and zinc enter used oil primarily in various additive packages included in commercial motor oil. Cadmium and chromium enter oil in trace amounts, primarily as a result of engine wear; however, some additives may also contain these metals. The source of arsenic in used oil has not been determined.

Lead is present in higher and wider ranges of concentrations than the other metals (0 to 21,700 ppm).* Typically, mixed used oils in the 1980s will have a lead concentration between 100 and 1,200 ppm. Although higher lead levels can still be found in 1983, the overall presence of lead is decreasing as unleaded gasoline continues to comprise a larger fraction of the total gasoline market. A recent EPA proposal to hasten the lead phasedown in gasoline by 1986 should significantly decrease the lead concentrations reported in Table 2. EPA's proposed regulation would reduce lead concentration from 1.1 g/gal to 0.1 g/gal by 1986 (45).

Other trace metals usually occur at lower concentrations. Barium concentration in used oil generally ranges from 50 to 500 ppm, but levels up to 3,906 ppm have been reported. Cadmium concentrations above 10 ppm are rare, with typical levels occurring around 2.0 ppm. Chromium concentration is generally higher than cadmium, with typical levels ranging from about 3 to 30 ppm. Arsenic was detected in 25 percent of the samples. Concentrations were significant when detected, with typical levels between 5 and 25 ppm. The techniques used for arsenic analysis are reported to significantly influence percent detection and measured concentrations. For this reason, scientists believe arsenic may be present more frequently than the data suggest (41). Zinc concentrations are high in used oils, typically ranging from 100 to 1,200 ppm. This is the only metal that typically occurs at levels close to that of lead.

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* This range of lead concentrations is based upon data reported from 1979 to 1983. The upper end of the range is atypical for this period and is more representative of levels found ten years ago.

1.4.2 Chlorinated Solvents Concentrations in Used Oils

Chlorinated solvents are a major group of contaminants in used oil. They are not a normal component of crankcase oil, but are indirectly introduced through careless or ignorant management practices by generators and collectors. For example, automobile mechanics often pour small amounts of degreasing solvents into tanks used primarily for storing used automotive oils.

Five chlorinated solvents are commonly detected in used oils. These include dichlorodifluoromethane, trichlorotrifluoroethane, 1,1,1-trichloroethane, trichloroethylene, and tetrachloroethylene. Levels of contamination appear random, ranging from less than 100 to several thousand ppm.

A method for assessing the presence of chlorinated solvents is to measure total chlorine. Although chlorine can be present in other forms, such as inorganic salts, this measure is an indicator of the contamination by potentially hazardous chlorinated substances. The data indicate that typical chlorine concentrations range from 1,000 to 5,000 ppm; however, much higher chlorine contents have been measured (over 40 percent of the oil by weight).

1.4.3 Other Organics Concentrations in Used Oils

This general category includes aromatic solvents, PNAs, and PCBs. Except for PCBs, used oils are likely to contain contaminants of this group. Only one-third of the samples showed detectable levels of PCBs.

Aromatic solvents are in used oils because of the inherent properties of the oil, oil use, and mixing with spent solvents. Toluene and xylene typically range from 500 to 5,000 ppm, but levels above 10,000 ppm have been measured. Benzene concentration is lower and typically ranges from 100 to 300 ppm.

The concentration of benzo(a)pyrene and benzo(a)anthracene range from below detection levels to several hundred ppm. These PNAs are present in unused lube oils, but they seem to become concentrated in used automotive oils, "apparently coming from the gasoline or diesel fuel and their combustion products" (21). Typical levels of benzo(a)anthracene range from 10 to 50 ppm; benzo(a)pyrene typically ranges from 5 to 20 ppm. Naphthalene, another PNA, was found in every used oil sample at much higher levels (110 to 1,400 ppm).

Although PCBs were not detected in about two-thirds of all used oils, 25 percent of the analyzed samples may have had concentrations above 15 ppm. Ten percent of the samples may have had levels above 50 ppm.* Several samples were identified with more than 100 ppm PCB.

1.4.4 1983 U.S. EPA Used Oil Sampling Program

In 1983, the U.S. EPA carried out a used oil sampling and analysis program to supplement the data obtained from other sources. Approximately 350 samples were taken; however, analytical results were only available for about two-thirds of the samples due to various reasons such as bottle breakage, or a very high water content. The results of these analyses are included in the overall summary in Table 2 and in the related discussion presented in the preceding section.

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* It was assumed that non-detected levels were equal to the analytical detection limits.

Table 3 presents a statistical summary of these data alone and some noteworthy differences are addressed in this section. Any differences which exist in the data in Tables 2 and 3 indicate an even greater difference between the EPA results and the other results because the EPA data are included in the total summary.

The measured levels of most contaminants were lower in the EPA data (Table 3), sometimes significantly. Metals (except lead) and total chlorine are lower by fairly significant amounts. Differences in chlorinated and organic solvents appear minor for the two summaries except for a few very high concentrations in the non-EPA samples. PCBs were detected in fewer of the EPA samples than in the other data; however, it should be noted that a large series of samples not in the EPA group were measured for PCBs using a lower detection level than the 5 ppm limit used in the EPA analyses.

Overall, the only significant difference in the data is the metals and chlorine levels which may be somewhat overstated in the total summary. The reason for the differences can only be hypothesized and may be due to the sampling methods which could have been more random in the EPA program and less likely to have been selected due to a belief that the oil was contaminated.

1.4.5 Concentration of Priority Pollutants in Used Oils

As part of the EPA survey described in the preceding section, 49 selected used oil samples were analyzed for priority pollutants including acid and base/neutral compounds, pesticides, and other listed hazardous

Table 3

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN SAMPLES OBTAINED UNDER 1983 EPA SAMPLING PROGRAM

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	206	5	2	6.24	5	5	5	<3	7.6
Barium	207	197	95	44.87	20	42	95	<0.5	770
Cadmium	207	112	54	1.5	0.57	1.2	1.7	<0.2	8.8
Chromium	207	170	82	13.01	2.9	5.3	9.1	<0.2	690
Lead	207	179	86	631.77	150	810	1,300	<0.5	3,700
Zinc	209	208	99	425.68	280	750	1,100	<0.5	1,800
Chlorinated Solvents									
Dichlorodifluoromethane				NOT MEASURED					
Trichlorotrifluoroethane				NOT MEASURED					
1,1,1-Trichloroethane	212	83	39	2,960.46	16	160	2,000	<1	62,000
Trichloroethylene	212	59	27	2,380.05	15	32	200	<1	37,000
Tetrachloroethylene	212	90	42	1,238.37	16	83	800	<1	21,000
Total Chlorine	216	203	93	3,438.9	1,000	2,100	6,100	<100	86,700
Other Organics									
Benzene	209	96	45	1,148.76	16	110	330	<1	55,000
Toluene	212	169	79	2,033.96	250	940	3,500	<1	55,000
Xylenes	212	172	81	2,375.91	500	1,200	2,900	<2	57,000
Benzo(a)anthracene				NOT MEASURED					
Benzo(a)pyrene				NOT MEASURED					
Naphthalene				NOT MEASURED					
PCBs	206	13	6	496.39	5	5	5	<0.5	3,800

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

compounds. A thorough presentation of these results is presented in subsequent sections of this report on specific oil types. A summary of the presence of frequently detected compounds is shown in Table 4. It should be emphasized that nearly 100 specific priority pollutants were detected in at least one of the 49 samples. These pollutants and their concentrations are included in the detailed summaries presented later in this report.

Fairly high levels of the priority pollutants shown in Table 4 and many others, are routinely found in used oils. In most cases, the presence of these compounds is related to the inherent properties of lubricating oils, but also to the fuels burned in engines using the oils.

1.5 USED OIL PROCESSING RESIDUES

As a result of normal operations, used oil collectors, processors, and re-refiners generate residues which contain the hazardous constituents which were present in their collected oil. Table 5 lists the seven major residues which are generated by the used oil management system along with maximum annual generation and typical management practices. It is important to emphasize that residue generation rates and management practices vary tremendously with the used oil management system. The maximum estimates for generation shown in Table 5 are based upon reported conditions and practices for various facility types. The actual annual generation volumes are probably less than the values shown.

The management practices show that some residues are typically handled as if they were hazardous; others are not treated in that manner. Table 6 provides some data on the presence of hazardous constituents in

Table 4

SUMMARY OF THE PRESENCE OF SOME FREQUENTLY DETECTED PRIORITY POLLUTANTS IN USED OIL

Pollutant	Number Detected*	Percent Detection	Mean (ppm)†	Range (ppm)
Naphthalene	33	67	644	ND‡ to 2,480
Phenanthrene	35	71	252	ND to 2,080
Pyrene	10	20	141	ND to 470
Fluorene	19	39	167	ND to 530
2-Methylnaphthalene	33	67	937	ND to 2,700

* Out of a total of 49 samples; does not include "trace" levels.
† Mean is calculated for detected levels only.
‡ ND: Not detected at 50 ppm detection level.

Source: Franklin Associates, Ltd. from (48).

Table 5

RESIDUE GENERATION AND MANAGEMENT IN THE USED OIL INDUSTRY*

Residue type	Annual generation	Typical management practices†
In-line filter residue	Up to 380 tons	Sanitary landfill
Settled wastewater	Up to 210 million gallons	Sanitary sewer system, evaporation ponds
Oily sludge	Up to 25 million gallons	Hazardous and sanitary landfill, other treatment/recovery facilities
Tank bottoms	Up to 5 million gallons	Hazardous and sanitary landfill
Centrifuge/filter screen solids	Up to 6 million gallons	Hazardous and sanitary landfill, blended into oil
Spent clay	Up to 22,000 tons	Sanitary landfill
Acid sludge	Up to 2.3 million gallons	Hazardous landfill

* Uncertainties exist in residue quantities because of a lack of detailed data on the number of facilities and specific processing technologies used, and variable oil quality.

† Only common management methods are shown. See Figures 6 to 9 for a more detailed description of residue generation and management alternatives.

Source: Franklin Associates, Ltd. based upon estimated number of facilities (Table 1) and typical residue generation rates (Table 35).

Table 6

CONTAMINATION OF USED OIL PROCESSING RESIDUES*

Constituent	Settled Sludges Median (ppm)	Settled Sludges Range (ppm)	Wastewater Median (mg/1)	Wastewater Range (mg/1)	Spent Clay Median (ppm)	Spent Clay Range (ppm)	Distillation Bottoms Median (ppm)	Distillation Bottoms Range (ppm)
Metals								
Arsenic	<5	ND†-24	0.10	ND-22	3.7	ND-24	1	ND-15
Barium	70	ND-3,600	1.0	ND-300	76	ND-628	25	6-1,400
Cadmium	<7	ND-216	0.55	ND-37	11	0.5-13	9	ND-29
Chromium	20	ND-2,130	1.04	ND-68	17	5-169	35	7-100
Lead	300	ND-7,770	5	ND-2,300	1	ND-1,200	4,235	1,090-15,000
Zinc	259	ND-3,150	5.5	ND-1,650	76	52-800	133	85-3,500
Chlorinated Solvents								
Dichlorodifluoromethane	22	ND-640	-	-	-	-	-	-
1,1,1-Trichloroethane	300	ND-110,000	250	ND-1,900	-	-	-	-
Trichloroethylene	100	ND-1,300	100	ND-2,600	-	-	-	-
Tetrachloroethylene	200	ND-8,200	110	ND-1,300	-	-	-	-
Total Chlorine	1,780	88-181,000	1,140	76-4,170	-	-	-	-
Other Organics								
Benzene	-	-	290	ND-890	-	-	-	-
Toluene	-	-	693	14-5,800	-	-	-	-
Benzo(a)anthracene	-	-	ND	ND	-	-	-	-
Benzo(a)pyrene	1.4	ND-12	ND	ND	-	-	-	-
Naphthalene	-	-	229	ND-700	-	-	-	-
PCBs	17	ND-500	0.19	ND-14	-	-	-	-
Phenol	-	-	5,100	ND-99,000	-	-	-	-

* Limited data are available on the contamination of other residues including tank bottoms, filter and centrifuge solids, and re-refining sludges (see Section 4.4 and Appendix B).

† ND: Not detected.

Source: Data reported and referenced in Appendix B.

three residues (settled sludges, wastewater, and spent clay) and on a marketable byproduct (distillation bottoms). Note that both wastewater and spent clay are usually not managed as though they were hazardous.

The median and range of concentrations for the hazardous constituents are shown in Table 6. The data show that the presence of potentially hazardous constituents in settled sludges is not very different from those levels measured in used oils (Table 2). This is not surprising since the oil content in these sludges can be more than 50 percent. The composition data show that a settled sludge can contain several listed hazardous constituents. However, the contaminants do not appear to concentrate in the settled sludges.

The differences in wastewater composition and used oil composition are dependent upon the solubility of the constituents in the water and oil phases. The metals tend to remain in the oil rather than settle with the wastewater. The low median metals concentration in the wastewater is due to the small amount of oil which remains in the separated water fraction. The chlorinated and aromatic solvents show fairly high concentrations in the wastewater, but not significantly different from those found in the oil. Solubility of these contaminants is similar in both phases. One-fourth of the wastewater samples were found to contain PCBs. No PNAs were detected in wastewater, but the data were limited (only two samples were analyzed).

Data on spent clay contamination are for metals only. The levels of contamination vary and are dependent on how the clay was used. Metals content is lowest in spent clays used to polish lube oils from distillation/

clay re-refining processes. The highest levels are reported for clay used in contact filtration processing and chemical treatment/clay bead re-refining. Intermediate levels have been measured in clays from acid/clay re-refining facilities.

It is believed that most spent clays have insignificant levels of chlorinated and aromatic solvents because these contaminants are separated from the used oil prior to contacting the clay. A possible exception is spent clay used in a contact filtration process (this is an uncommon practice). Higher molecular weight hydrocarbons such as PCBs and PNAs have not been measured, but their presence in spent clay is probable at levels directly related to their concentration in the used oil. Therefore, significant contamination by these constituents is possible.

Comparative data are available on metals concentrations in distillation bottoms. A single analysis was performed to measure PCBs and PNAs content; neither of these constituents was detected (detection limits were 11 ppm for PCBs and 4 ppm for benzo(a)pyrene and benzo(a)anthracene). The results of five metals analyses in distillation bottoms indicate that fairly high levels of each metal are present. The distillation process concentrates the metals from the used oil into the bottoms material. Therefore, the metals content is directly related to levels in the used oil.

1.6 STUDY HIGHLIGHTS

The major highlights of this research effort are listed in this section. These highlights were taken from all five sections of the report.

1. About 1.2 billion gallons of used oil were generated from sales of over 2.3 billion gallons in 1983. About 58 percent (699 million gallons) was generated from automotive sources and 42 percent (507 million gallons) from industrial sources. The non-generated oil is lost or consumed during use.
2. Only 55 percent (669 million gallons) of the generated used oil enters the used oil management system, which is comprised of collectors, processors, and re-refiners. The types of companies involved in used oil management differ considerably in size, processing technology, markets, and oil types received. In total, about 1,000 companies participate in used oil management in the United States.
3. Collected and processed used oil is marketed primarily as a fuel oil (about 590 million gallons in 1983). About half of the burned used oil is blended with virgin fuel oil products. Other major reuse markets include road oil (69 million gallons) and re-refined lube products (63 million gallons). Minor markets, which include flotation oils, asphalt extenders, and form oils, consumed 35 million gallons in 1983.
4. This study characterized used oil contamination by 19 specific hazardous constituents. The results of 1,071 analyses* indicate that high levels of

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* The constituents measured in each oil sample varied from only one to over 50 including all nineteen hazardous constituents.

contamination are common for many constituents including lead, chromium, cadmium, and several chlorinated solvents. PCB contamination was detected in about 18 percent of the analyses.

5. Used oil processing produces residues which are significantly contaminated by the same hazardous constituents found in the oil. The major residues include wastewater separated from used oil, settled sludges, tank bottoms, spent clay, centrifuge and filter solids, and acid-sludge.
6. Automotive used oils tend to have higher concentrations of potentially hazardous heavy metals; industrial oils tend to have higher levels of chlorinated solvents and PCBs. No significant differences were noted in the concentrations of aromatic solvents or polynuclear aromatics (PNAs).
7. Used oils from gasoline engines have much higher lead concentrations than those from diesel engines due to the presence of lead in some gasoline additives. As leaded gasoline usage decreases, and as the lead level in leaded fuels decreases in accordance with proposed EPA rules, this difference in lead concentration will also decrease.
8. Metalworking industrial oils are believed to have higher levels of heavy metals and chlorinated solvents than other industrial oils, including hydraulic, compressor, turbine, electrical, and others.
9. About 30 percent of the oil samples had a measured flash point below 140°F, which is a criterion for classifying a waste as hazardous. Since virgin lube oils have a flash point above 350°F, the low flash points must be due to contamination by low flash point materials such as gasoline, and chlorinated and organic solvents.

10. Although limited data indicate that processing technologies such as settling, centrifugation, and filtration reduce metals concentrations in used oils, the analytical results of hundreds of samples show that the average contamination levels in unprocessed used oils are somewhat lower than the levels in processed oils. Only chromium, PCBs, and 1,1,1-trichloroethane concentrations are lower in processed oil. Overall, processing does not appear to significantly affect the concentration of hazardous materials in used oil.

11. The used oils burned as fuel have much higher levels of hazardous constitutents than any virgin fuel oil products. Virgin fuel oils have very low heavy metals and PNA concentrations, and no chlorinated solvents compared to relatively high concentrations for all these materials in used oils.

12. Used oils do not appear to differ significantly in contaminant levels according to end-use markets. Similar levels of contamination were measured in used oils which were burned, road oiled, and re-refined.

SECTION 2

DEFINITIONS

2.1 OIL

Oil is a complex mixture of hydrocarbons that lacks a defined chemical structure. It contains mixtures of isomers* and three or more members of a homologous series** which differ by a fixed carbon containing increment (21,42).

2.2 CRUDE OIL

Crude oil is a hydrocarbon mixture which occurs naturally in the earth (adapated from 43 CFR 3000.0-5).

2.3 SYNTHETIC OIL

There are two sources of synthetic oils: (1) those derived from petrochemicals; and (2) those derived from coal or shale oil.

1. Synthetic oils derived from petrochemicals are chemically combined low molecular weight compounds which are used as lubricants.

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* Isomers are molecules having the same number and kind of atoms, but differing with respect to atomic arrangement.

** A homologous series is a series of compounds in which each successive member differs from the preceding member by a fixed increment in certain constituents. For example, CH_3OH (methanol), C_2H_5OH (ethanol), and C_3H_7OH (propanol) form a homologous series with carbon atoms increasing by one.

2. The crudes derived from coal and shale oil on an industrial scale (in the future) will vary in composition just as the naturally occurring crude oils vary. Most of the crude from these sources will be refined for fuels and, not for lubricant use.

2.4 LUBRICATING OIL

Natural lubricating oils are separated from crude oil using sophisticated refining processes including vacuum distillation, deasphalting, dewaxing, and finishing or polishing. This separated group of middle distillate hydrocarbons is either naphthenic or paraffinic in character. Naphthenic lube oils contain primarily cyclic hydrocarbon molecules, whereas paraffinic lube oils contain primarily long-chain carbon molecules. Naphthenic oils have the advantage of a naturally low pour point and good thermal stability; paraffinic oil is more resistant to oxidation, but often has to be dewaxed to achieve fluidity (15).

2.5 PROCESS OIL

Process oils are formulations of liquid hydrocarbon mixtures (primarily lubricating oils) in which the oil becomes an integral part of a produced product. For example, lube oil stocks provide much of the material requirements in the manufacture of rubber, ink, paint, putty, polishes, and many other oil-based products. Only small amounts of process oils become "used oils"; most of this generation results from spillage.

2.6 EMULSIFIED OIL

Emulsified oils are an oil-water mixture with an addition of small amounts of emulsifying chemicals and biocides. Most emulsions contain from 2 to 10 percent oil; however, higher oil fractions are sometimes used in some applications (e.g., hydraulic oils). Most emulsified oils are used as lubricants and coolants in metalworking applications, but a significant volume is also used in the hydraulic fluid market, particularly where fire resistance is desirable.

2.7 OILY WASTEWATER

A dilute mixture of oil in water generated through such processes as equipment washdown, yard runoff, or general processing.

2.8 USED OIL

Used oil is a hydrocarbon mixture which has been refined from crude or synthetic oil and used in a non-consuming application (i.e., as a lubricant). As a result of use, the oil becomes contaminated by physical or chemical impurities and must be removed from service (RCRA Section 1004 (43)).

2.9 WASTE OIL

In this document, waste oil is a petroleum-derived oil which through use, storage, or handling has become unsuitable for its original purpose. In addition to used oils (defined above), unused petroleum wastes are also classified as waste oil. Unused oil generally becomes a waste oil when it is spilled, when it mixes with other wastes (e.g., a ship's ballast water), or when it fails specifications for its intended use and is discarded (e.g., ASTM specifications for fuel oils) (21).

2.10 USED OIL GENERATOR

A used oil generator accumulates used oil in an on-site storage container, usually a drum or a steel tank. Generated oil may be reused on-site, but it is usually picked up by a collector for off-site processing and/or reuse. A generator may accumulate only oil which has been generated on-site (e.g., new car dealers, fleet shops, etc.), or may accumulate used oil generated off-site as well (e.g., recycling centers or service stations).

2.11 USED OIL MANAGEMENT SYSTEM (U.O.M.S.)

The used oil management system consists of companies involved in the generation, collection, processing, transport, and reuse of used oils. In combination, these companies interact with one another to provide the mechanism for used oil to flow from its point of generation to its ultimate reuse or disposal. Some companies are involved in just one function (primarily the generators) but many participate in more than one aspect of this industry. For example, virtually all processors also collect used oil from generators.

2.12 INDEPENDENT COLLECTOR

Independent collectors are members of the used oil management system who collect used oil from generators, but do not process the oil to remove any contaminants. Independent collectors may store used oil and sell the material to re-refiners, processors, or directly to end-use markets such as burning, fuel oil dealers, and road oiling.

2.13 MINOR PROCESSOR

Minor processors are members of the used oil management system who collect used oil from generators and separate water and some solids from the oil using simple settling technology with or without heat addition. Processed oil is sold primarily directly to markets including fuel oil dealers, burners, and road oiling with some sales going to major processors and re-refiners.

2.14 MAJOR PROCESSOR

Major processors are members of the used oil management system who collect used oil from generators; who may buy used oil from independent collectors; and who process the oil to remove water and solid contaminants. Processing technologies differ and include various combinations of several available methods including screen filtration, heated settling, centrifugation, light fraction distillation, and blending. Processed oil is sold to fuel oil dealers, direct to burners, as road oil, and to other miscellaneous users.

2.15 RE-REFINER

Re-refiners are the most sophisticated members of the used oil management system with respect to processing technologies. These companies collect used oil from generators or buy used oil from independent collectors. The oil is processed to give a recycled lube oil capable of being reused for its original purpose. A light hydrocarbon fuel is produced as a coproduct of each of the four or five basic re-refining technologies currently in operation in the United States.

2.16 USED OIL PROCESSING RESIDUES

Minor processors, major processors, and re-refiners generate used oil processing residues as a result of removing contaminants from the used oil. There are a few major processing residue streams common to most processor company types including oily wastewater, in-line filter residue, and tank bottoms. Other residue streams are specific to processing technologies utilized and include such things as centrifuge solids, filter screen sludge, acid sludge, and spent clay.

2.17 PRODUCT OIL

The used oil which has been cleansed of some contaminants by minor and major processors is referred to as product oil. Product oil quality varies tremendously based upon processing technologies and the quality of the unprocessed used oil received at the facility.

Section 3

USED OIL GENERATION IN THE UNITED STATES

3.1 OVERVIEW

This section presents a description of used oil generation and management practices at the generator site as it existed in 1983. In addition, some description of specific oil types and applications is included. The composition of used oil and unused oil is presented with respect to basic hydrocarbon components and contaminants. The presentation of information begins with a description of unused oils and progresses to used generation, composition, and management practices.

3.2 CHARACTERIZATION OF LUBRICANTS AND INDUSTRIAL OILS

3.2.1 Source of Lubricating Oils

All lubricants and industrial oils are comprised of a mixture of hydrocarbon compounds which are either separated from the complex mixture of hydrocarbons occurring in natural crude oil or synthetically manufactured from chemical feedstocks. Synthetic lubricants are more uniform in composition than the straight mineral oil lubricants derived from crude. In 1983, synthetic lubes comprised only a few percent of the total lubricant market, primarily used in high temperature applications such as aircraft turbines and internal combustion engines.

The crude oils from which straight mineral lubricants are derived can be divided into three main groups based on their predominant hydrocarbon structures: paraffinic, naphthenic, and aromatic. The class of paraffinic crude oils contain mostly saturated straight and branch-chained carbon compounds (alkanes), along with lesser amounts of cycloalkanes and aromatics. Naphthenic crudes contain appreciable quantities of compounds with at least one saturated ring structure (cycloalkanes). Aromatic crude oil contains a large concentration of unsaturated benzene structures. The varying proportion of these three classes of compounds (alkanes, cycloalkanes, and aromatic hydrocarbons) determines the physical and chemical properties of crude oils. They may be an indicator of relative levels of some hydrocarbons which are potentially hazardous (carcinogenic) constituents of crude oil which are often aromatic in nature.

Table 7 summarizes the levels of some potentially hazardous constituents (including non-hydrocarbons) which have been identified in crude oil. Arsenic, cadmium, and zinc appear commonly and at relatively high concentrations. Chromium and lead are present at much lower levels.

The concentration of benzo(a)anthracene and benzo(a)pyrene (two carcinogenic aromatics) have been measured in several crude oils. Values between 1.0 and 2.0 ppm are most common.

Total chlorine in crude oil is variable, ranging from less than 1.0 to 1,010 ppm. In crude oil, chlorine is usually present in the form of inorganic salts, which are removed as part of refining.

3.2.2 Unused Lube Oil Characteristics

Like the crude oil from which they are derived, the straight mineral oils which comprise lubricant basestocks contain a complex mixture of hydrocarbons. The composition of the hydrocarbon mixtures depends largely on the area where the crude oil originated. Straight mineral oils are mixtures of paraffins, naphthalenes, and aromatics. A high paraffin fraction

TABLE 7. PRESENCE OF SOME POTENTIALLY HAZARDOUS MATERIALS IN CRUDE OILS

Constituent	Range of reported concentrations (ppm) Low	Range of reported concentrations (ppm) High	Mean concentration* (ppm)	Other sample characteristics
Metals				
Arsenic	0.002	9.83	1.27	67% <1.0 ppm
Cadmium	0.0003	25.2	5.90	50% <1.0 ppm
Chromium	0.0016	2.76	0.63	80% <1.0 ppm
Lead	0.17	0.31	0.24	100% <1.0 ppm
Zinc	0.4	86.0	15.8	44% <1.0 ppm
Organics				
Benzo(a)anthracene	0.1	2.8	1.33	30% <1.0 ppm
Benzo(a)pyrene	0.4	2.8	1.38	40% <1.0 ppm
Total Chlorine	0.39	1,010	152.6	40% <10 ppm

* Midpoints of reported concentration ranges were used to calculate means.

Source: (23-29).

makes the oil more resistant to oxidation, whereas a high aromatic fraction gives the oil better thermal stability. Additive packages, which are described later in this section, are often used in mineral oils to enhance performance characteristics. White oils are mineral oils from which all aromatic hydrocarbons are removed. White oils are transparent, colorless, odorless, and tasteless when cold. They are used for medicinal purposes, as food additives, as finishing oils, and for other uses requiring a very pure lubricant.

White oils usually do not become part of the used oil management system because they are typically consumed in use or in some cases disposed of with other wastes.

The hydrocarbon constituents of lube basestocks are classified according to the three basic groups in Table 8: alkanes, cycloalkanes, and aromatics. The aromatic fraction, which ranges from 10 to 30 percent by weight, is of greatest interest because most known carcinogens can be found in this category. An important distinction is the difference in the water solubility of different types of hydrocarbons. Water solubility increases from alkanes, to cycloalkanes, to aromatics. For example, benzene (an aromatic) has a saturation solubility of 1,800 ppm in distilled water, whereas the alkane of equivalent molecular weight has a saturation of 10 ppm.

Limited data are available regarding the presence of hazardous constituents in unused lube oil base stocks. These data, which are summarized in Table 9, show that the concentrations of all heavy metals are very low. Benzo(a)pyrene concentration is also low (<1 ppm) but it is likely to be present in most lube oils.

TABLE 8. HYDROCARBON COMPOSITION OF LUBRICATING OIL STOCKS*

Hydrocarbon type	Percent (by weight)
Alkane	45-76
Cycloalkane	13-45
Aromatic	10-30

* Represents composition of straight mineral oils except white oils.

Source: (21).

TABLE 9. HAZARDOUS CONSTITUENTS IN LUBE OIL BASE STOCKS*

Constituent	Concengration Range (ppm)	
	Low	High
Metals		
Barium	0	1.0
Cadmium	<0.8	0.2
Chromium	0	0.05
Lead	0	1.0
Zinc†	1.0	1.0
Benzo(a)pyrene	0.03	0.28

* The data shown in this table were developed from only five sample tests.

† Only two samples analyzed zinc concentration, each showing levels of 1 ppm.

Source: (29, 31, 32).

3.2.3 Lubricant Additives

Various compounds are blended into virtually all lubricating oils to improve the effectiveness of the lubricant and to prolong its period of effectiveness. The additive package usually comprises 10 to 20 percent of the volume of the finished lube products; therefore, the compounds which are added can greatly influence lube oil composition. Table 10 describes the basic types of additives as well as their general composition, application, and function. Most additive packages contain a combination of several specific types of additive compounds as shown by the example formulation shown in Table 11 for typical gasoline engine oil. In this case, the base oil comprises 86 percent of the volume of the finished product and four different additives comprise the remaining 14 percent.

It is clear that the presence of hazardous constituents in lubricating oils is affected by additives. Several metals are present in additives including barium, chromium, zinc, and even lead. In addition, several sulfur, chlorine, and nitrogen containing compounds are commonly included in additive packages.

There has been little published comprehensive analytical testing of finished lube oil products. Table 12 summarizes the results of several limited analyses. A comparison of the data in Table 12 with that presented for lube oil base stock (no additives) in Table 9 indicates that barium and zinc concentrations increased significantly with additives. Lead levels appear slightly elevated.

TABLE 10. COMPOSITION, APPLICATION, AND FUNCTION OF LUBRICATING OIL ADDITIVES

Name of Additive	Composition	Application	Function
Corrosion Inhibitor	Zn and Ba dithiophosphates, dithiocarbamates, metal sulfonates, and sulfurized terpenes	IC engines, alloy bearings, ATF	To react with metal surfaces to form a corrosion-resistant film
Rust Inhibitor	Sulfonates, alkylamines, amine phosphates, alkenylsuccinic acids, fatty acids, and acid phosphate esters	IC engines, turbines, electric and mechanical rotary machinery, fire-resistant hydraulic fluids	To react chemically with steel surfaces to form an impervious film
Antiodorant	Perfumes, formaldehyde compounds	With EP additives	To mask odors
Antiseptic	Alcohols, phenols, chlorine compounds	With water added to oil-emulsions	To inhibit microorganisms
Antioxidant	Sulfides, phosphites, amines, phenols, dithiophosphates	IC engines, turbines, and rotary machinery	To inhibit oxidation of oil
Antifoam	Silicones, synthetic polymers, waxes	Same as rust inhibitors, excluding ball bearings	To permit air bubbles to separate from oil
Detergent	Sulfonates, phosphonates, phenates, alkyl substituted salicylates combined with barium, magnesium, zinc calcium	IC engines understeady load	To neutralize acids in crankcase oils to form compounds suspended in oil
Dispersant	Alkenyl succinimides, alkylacrylic polymers, ashless compounds	IC engines at low temperatures and variable loads	To disperse contaminants in the lubricant

Abbreviations: IC = Internal Combustion Engine; ATF = Automatic Transmission Fluid; EP = Extreme Pressure.

Source: (21 and 33).

TABLE 10. COMPOSITION: APPLICATION, AND FUNCTION OF LUBRICATING OIL ADDITIVES (continued)

Name of Additive	Composition	Application	Function
Metal Deactivator	Organic dihydroxyphosphines, phosphites, and sulfur compounds	IC engines, turbines, electric motors, air compressors, hydraulic oils	To form protective film on running surfaces to inhibit corrosion reactions
Color Stabilizer	Amine compounds	When heat and oxidation darken oil	To stabilize oil color
Viscosity Index Improver	Isobutylene polymers and acrylate copolymers	IC engines, electric motors, air compressors, hydraulic oils	To retard loss of viscosity at high temperatures
Pour Point Depressant	Polymethacrylates, polyacrylamides, alkylated naphthalenes and phenols	IC engines, gears, bearings, transmissions	To prevent congealing of oil at low temperatures
Extreme Pressure Additives	Organic compounds with sulfur, phosphorous, nitrogen, halogens, carboxyl or carboxalate salt	IC engines, turbines, motors hydraulic oils, gears, rollers and ball bearings	To form low-shear-strength film providing lubrication at startup and at high bearing loads
Antiwear Additive	Chlorinated waxes, organic phosphates, lead naphthenate	As above	As above except for running condition
Tackiness Agent	Polyacrylates and polybutenes	Gear enclosures from which oil must not drop	To improve adhesive qualities of base oil
Emulsifier	Surfactants, sulfonates, naphthenates and fatty acid soaps	Soluble cutting oils	To reduce interfacial tension and permit formation of water-oil emulsion

Abbreviations: IC - Internal Combustion Engine: ATF = Automatic Transmission Fluid; EP = Extreme Pressure.

Source: (21 and 33).

TABLE 11. TYPICAL FORMULATION OF GASOLINE ENGINE OIL

Ingredient	Percent of Volume
1. Base Oil (solvent 150 neutral)	86
2. Detergent Inhibitor (ZDDP-zinc dialkyl dithiophosphate)	1
3. Detergent (barium and calcium sulfonates)	4
4. Multi-functional Additive (dispersant, pour-depressant, viscosity improver - polymethyl-methacrylates)	4
5. Viscosity Improver (polyisobutylene)	5
	100

Source: (1).

TABLE 12. HAZARDOUS CONSTITUENTS IN FINISHED LUBE OILS*

Constituent	Concentration Range (ppm) Low	Concentration Range (ppm) High
Metals		
Barium	1.2	162
Cadmium	0	-
Chromium	0	-
Lead	0	3
Zinc	359	2,440
Total Chlorine	-	155‡
Benzo(a)pyrene†	0.03	0.28

* Contains additive packages.
† Not known if additives are present in analyzed samples.
‡ Only one sample was analyzed for total chlorine.

Source: (5).

3.2.4 Classification of Lubricating and Process Oils

For the purposes of this study, two broad classifications are used for lubricating and process oils: automotive and industrial. These major categories are described in the following sections.

3.2.4.1 Automotive Oils

Automotive oils include a wide variety of products used in numerous applications. Basic types of automotive oils include:

- Engine (crankcase) oils
- Transmission fluids (includes power-steering fluid)
- Diesel engine oils
- Automotive hydraulic fluids (primarily brake fluids)

In 1983, an estimated 1.225 billion gallons of automotive crankcase and hydraulic oils were sold (44). About 60 percent (732 million gallons) were engine oils for over-the-road cars and trucks. About 252 million gallons were engine oils for off-road vehicles such as farm, construction, military, and mining vehicles. Automotive hydraulic oil sales were 192 million gallons while transmission oil sales were only 49 million gallons (44). In addition, 26 million gallons of automotive greases were sold, but none is generated as a collectable waste (44).

Gasoline and diesel engine oils are classified according to the service for which the oil is intended and the corresponding additive levels that are required. The American Petroleum Institute (API) has developed five gasoline engine oil classifications including SA (non-detergent), SB, SC, SD, and SE. Four diesel engine oil classifications are used including CA, CB, CC, and CD. Most gasoline engine oils are classified as SE; most diesel engine oils are CC or CD. Detailed descriptions of each oil service classification are available, but not included in this report (see Reference 15).

3.2.4.2 Industrial Oils

There are hundreds of lubricating oil formulations used in thousands of industrial applications. Most of these formulations can be classified according to the 12 major industrial oil categories listed below:

- Hydraulic
- Compressor
- Turbine
- Bearing
- Gear
- Metalworking (removing, forming, testing, protecting)

- Process
- Refrigeration
- Railroad Diesel
- Marine
- Natural Gas Engine
- Grease

Approximately 97 percent of the 1.061 billion gallons of industrial oils sold in 1983 were used in one of the above applications.

The process oil market was the largest single category of those listed above in 1983 (298 million gallons). Process oils are used in the manufacture of rubber, ink, paint, putty, polishes, and many other products as well as in electrical applications. The oil becomes an integral part of the process and for all practical purposes, it is consumed (i.e., not available for recovery and reuse).

For a specific end-use application, hydraulic oils were the largest market in 1983 (264 million gallons). There are two main types of straight mineral oil hydraulic oils which comprise about 96 percent of this market: rust and oxidation oil and antiwear oil (15). A growing market is fire resistant hydraulic fluids which are emulsified oils containing 60 to 95 percent water. The major users and generators of hydraulic oils are the steel, automobile, and mining industries. Municipal vehicles including snow plows, buses, street sweepers, dump trucks, and garbage trucks also use substantial amounts of hydraulic oils.

Metalworking oils are another major industrial oil category (163 million gallons in 1983). They are used as lubricants for cutting, grinding, machining, rolling, stamping, and quenching steel and aluminum, and to prevent rust and staining of these metals. There are three types of metalworking oils including straight mineral oils (neat oil - no water phase), emulsions (up to 95 percent water), and synthetic oils in emulsified form. Straight mineral oil formulations containing emulsifiers are often purchased by a user who adds water on-site. The quantity of emulsified metalworking fluids is many times larger than the 163 million gallons of straight mineral oils sold into this market.

Railroad and marine oils (57 and 49 million gallons, respectively, in 1983) are either cylinder or crankcase diesel oils which differ from other diesel engine oils in both basestock characteristics and additives. There are three classes of both rail and marine oils based upon service requirements. Natural gas engine oils are consumed in the thousands of gas-driven engines used primarily to drive irrigation and crude oil pumps.

Turbine oils (about 78 million gallons in 1983) are used in turbines to generate electricity or in compressors in ammonia plants, chemical plants, refineries, and other industrial facilities. They are similar in composition to hydraulic oils. Their use is decreasing because turbines require expensive natural gas as fuel and because large gas reciprocating engines are more efficient than the turbines. However, turbine oils will continue to be used in gas turbines for applications where size and weight considerations are important (e.g., aircraft, offshore drilling rigs, etc.).

Electrical oils (76 million gallons in 1983) act as heat transfer media in transformers to insure that the operating temperatures of the transformers do not exceed acceptable limits. Much of these sales were to replace

PCB oil which had previously been used for this purpose. Straight mineral oils (non-conducting material) are used with no additives.

Industrial gear lubricants (33 million gallons in 1983) are usually formulated with extreme pressure additives to minimize wear and prevent gear damage under a wide range of speed and torque conditions. Numerous types of industrial machinery contain gear boxes which use industrial gear lubricants specified by manufacturers. Also, the rear axle of cars and trucks and the transmissions and differentials of vehicles use gear oils.

3.3 USED OIL GENERATION

In virtually all lubricating and industrial applications, the performance of the oil deteriorates over a period of time as oil additives break down and as contaminants build up in the oil. At a certain point in time, the oil must be removed from service and replaced by new oil. Each of the thousands of specific oil applications is a generating source of used oil because of these routine replacement practices.

The fraction of the new oil which is generated as used oil at the point of use differs considerably. For example, only 10 percent of industrial process oils sold are generated as used oil compared to 90 percent of electrical transformer oils (1). The non-generated fraction of the oil is lost during use or handling as a result of leakage, spillage, combustion, disposal with equipment,* and disposal due to high levels of contamination. Overall, a little more than half of the lubricating and industrial oils which are sold are generated as used oil at the source.

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* Includes the disposal of electrical, cooling, and hydraulic oils with decommissioned equipment containing these oils.

The total volume of used oil generated in the United States depends on the quantity of new oil sold into each application. These sales data, along with generation rates for each application, can be used to develop the volume of total generated used oil. A summary of new oil sales in terms of 30 end-use applications is shown in Table 13. The data show that about 1.2 billion gallons of used oils are generated as a result of sales of over 2.3 billion gallons.

In 1983, total automotive sales were somewhat higher than industrial sales. Approximately 1.25 billion gallons of automotive oils and 1.06 billion gallons of industrial oils were sold (44). Sales in each of these major categories are broken down into specific oil applications in Table 13 for the purpose of estimating the volume of generated used oil (12 automotive applications and 18 industrial applications).

Overall, the generation rate for automotive oils is about 56 percent compared to just 48 percent for industrial oils. The relatively low generation rate for industrial oils is largely due to the very low generation rates for some metalworking and industrial engine oils, and process oils, all of which are major end-use markets.

It is important to emphasize in this section that the accuracy of the used oil generation factors is unknown and believed to be based upon theoretical considerations rather than measured values. For the purposes of this study, several documents were reviewed to acquire the best available information in this subject area (1, 10, 15, 20, 44).

TABLE 13. USED OIL GENERATION BY OIL TYPE, 1983

Oil type	New oil sales (10^6 gal)	Used oil generation factor*	Used oil generation (10^6 gal)
I. AUTOMOTIVE OILS			
On-Road Engine Oils			
Personal Vehicles			
DIYers	356.9	0.67	239.2
Non-DIYers	84.7	0.67	56.7
Commercial Vehicles			
Cars & Light Trucks	158.9	0.66	104.7
Trucks & Buses	139.7	0.59	82.4
Subtotal - On-Road	740.2		483.0
Off-Road Engine Oils			
Farm	74.1	0.59	43.7
Construction	68.8	0.59	40.6
Mining	45.5	0.59	26.8
Government	11.7	0.63	7.4
Aviation	12.7	0.47	6.0
Subtotal - Off-Road	212.4		124.5
Hydraulic Fluids			
On-Road Vehicles	79.0	0.10	7.9
Off-Road Vehicles	111.4	0.75	83.6
Subtotal - Hydraulics	190.4		91.5
Greases/Other Non-Generated Oils	108.0	0	0
Total - AUTOMOTIVE OILS	1,251.0	0.559	699.0
II. INDUSTRIAL OILS			
General Industrial Oils			
Hydraulic	264	0.80 (0.76)	211.2 (200)†
Gear	33	0.60 (0.59)	20.0 (19.6)
Other Specified			
Turbine Circ.	78	0.60 (0.59)	46.8 (45.9)
Refrigeration	6	0.33 (0.32)	2.0 (1.9)
Way	5	0.60	3.0
Compressor	4	0.60	2.4
Rock Drill Air Tools	3	0.60	1.8
Other	28	0.73	20.5
Subtotal - General Industrial	421		307.7 (295.1)
Industrial Engine Oils			
Railroad Diesel	57	0.20	11.4
Marine	49	0.50	24.5
Natural Gas	38	0.20	7.6
Subtotal - Industrial Engines	144		43.5
Metalworking Oils			
Metal Removing	85	1.00	85.0
Metal Forming	47	0.60	28.2
Metal Treating	19	0.60	11.4
Metal Protecting	12	0.10	1.2
Subtotal - Metalworking	163		125.8
Process Oils			
Electrical	76	0.90 (0.27)	68.4 (20.5)‡
White	56	0.10	5.6
Rubber	64	0.10	6.4
Other	102	0.10	10.2
Subtotal - Process	298		90.6 (42.7)
Industrial Grease	35	0	0
TOTAL INDUSTRIAL LUBRICANTS	1,061	53.5 (0.478)	567.6 (507.1)
GRAND TOTALS	2,312		1,206.0

* Generator factor equals the fraction available for collection into the used oil management system; it does not include oil which ends up in wastewater treatment sludges generated on-site at industrial establishments.

† Values in parentheses equal actual industrial oil generation assuming that all oil sold in any one year does not finish its life cycle in that same year. Thus, there is an accumulation of oil in use in our industrial/commercial system.

‡ The relatively low level of actual used electrical oil generation is due to the fact that much of electrical oil sales are to replace PCB oils in transformers. The generation of these PCB oils is not included in this value since these oils do not enter the UOMS.

Source: Sales data: (44).
Generation factors: (1, 10, 15, 44), and Franklin Associates, Ltd.

3.4 CHARACTERIZATION OF USED OIL GENERATORS

A used oil generator does not necessarily accumulate used oil for collection. For example, do-it-yourself oil changers (DIYers), agricultural and construction machinery operators, and small generators of industrial oils often dump or dispose of their oils rather than accumulate them or take them to a point of accumulation. Those oils do not become part of the used oil management system and are not available for reuse. In addition, some generators may use their own oil as a fuel supplement or a dust suppressant. These "in-house" reuse practices divert used oil from established practices.

Overall, only 55 percent, or about 669 million gallons, of the generated 1.2 billion gallons of used oil in 1983 were accumulated by generators and entered into the management system which is comprised of collectors, processors, re-refiners, and end-users. DIYers eliminated 167 million gallons of generated oil from the system and other generators eliminated an additional 370 million gallons (see Figure 2). Only 29 percent of the new oil sales was accumulated by generators and recovered by the used oil management system (669 million out of 2.3 billion gallons).

Table 14 summarizes the types and numbers of potential generators of used oil. The actual number of each type is lower than the potential numbers shown; however, data are not available on generator participation in the used oil management system.

The following two sections summarize management of used oils by generators including an assessment of storage practices, in-house usage, disposal, and sale into the management system. The third and fourth sections

TABLE 14. POTENTIAL NUMBER OF USED OIL GENERATORS

Generator		Number of establishments or sites
Automotive		
Recycling Centers		8,690
Service Stations		93,400
Repair Shops		53,100
Auto Dealers		26,000
Auto Centers		2,100
Fleet Shops		44,300
Airports		5,000
Subtotal - Automotive		232,590*
Industrial		
Major Industrial Generators†		
SIC		
24	Wood Products	34,483
25	Furniture & Fixtures	9,608
26	Pulp/Paper	620
27	Newspapers	10,220
28	Chemicals	4,059
30	Rubber/Plastic	11,800
31	Leather	376
32	Glass	465
33	Primary Metals	7,653
34	Fabricated Metals	33,776
35	Machinery	54,018
36	Electronics	17,114
37	Motor Vehicles	9,086
38	Instruments	7,133
39	Miscellaneous Manufacture	15,766
49	Electric Utilities	1,068
Subtotal - Major Generators		217,245
Marine Terminals		
Military		153
Commercial		500
Railroad Yards		430
Subtotal - Industrial		218,328
Grand Total		450,918

Source: Automotive Generators (46).
Industrial Generators - Franklin Associates, Ltd., from (6 and 47).

address contamination of generated used oils by potentially hazardous constituents. Generators are classified as either automotive or industrial. Automotive generators accumulate only automotive oils; however, industrial generators may accumulate both industrial and automotive oils.

3.4.1 Automotive Generators of Used Oil

There are literally millions of sources of used automotive oils in the United States. If the used oil is accumulated at the source, the source is classified as a generator. Some generators may reuse the accumulated used oil on-site; however, most sell their oil to a collector who is part of the used oil management system (U.O.M.S.). Nearly one-quarter million generators of used automotive oil exist compared to a much greater number of non-generator sources. The non-generator sources are primarily DIYers and equipment operators in the farming, construction, mining, and forestry industries. Only small amounts of oil generated by these sources are recovered. Most is either dumped on the ground or mixed with other solid waste for disposal.

On-site reuse of used automotive oils falls into four general categories: (1) burning directly in space heaters; (2) burning as a diesel fuel-used oil mixture in vehicle engines; (3) road oiling for dust control; and (4) mixing with fuel oil for burning in on-site boilers.

A recent EPA study reported that 33,900 waste oil heaters were sold (primarily to automotive used oil generators) from 1979 to 1983 (22). Since there are about 233,000 potential automotive used oil generators, this would indicate that 14 to 15 percent of those companies have waste oil heaters. It is likely that a significant number of these heaters are in fact owned by other individuals such as farmers, mining companies, or even individuals.

Some automotive used oil generators mix used oil with virgin diesel fuel at levels ranging from 2 to 10 percent used oil for burning in vehicle engines. This activity is primarily limited to trucking fleets, the U.S. military services, and some large off-road vehicle operators.

Some large construction, mining, and forestry companies use accumulated used oils for dust control on private roads. This on-site reuse activity has been decreasing in recent years (5).

The final direct use of used automotive oils is on-site burning in conventional boilers, primarily by U.S. military bases. Several documents have reported this activity which may consume up to 50 percent of the used automotive oils generated by the Department of Defense (see Appendix C for a more thorough discussion).

Most used automotive oils accumulated by generators is collected into the used oil management system. As shown in Table 14, several types of companies are involved in this practice, including:

- Service Stations
- Repair and Maintenance Shops
- Vehicle Dealers
- Fleet Shops
- Recycling Centers

In recent years, the service stations have lost their position as the major point of commercial crankcase oil changes to repair shops, rapid oil change services, and department stores.

Most of the used oil accumulated by automotive generators who sell their oil to the management system is generated on site. A small amount is brought to generators by DIYers, but this is only 14 percent of DIYer generation (10) and only about 5 percent of the total used automotive oil which is accumulated at these locations. A small amount of cleaning and degreasing solvents is routinely put into the oil by mechanics working at some generator sites. The nature and quantity of these materials are addressed in Sections 3.4.3 and 3.4.4. Some water may also enter stored oil through carelessness or faulty design of the storage system.

Used automotive oil generators accumulate between 100 and 2,500 gallons of oil per month with 500 gallons most typical. Most generators store used oil in 500-gallon underground tanks. Some generators pour oil into one or two 55-gallon drums, which may be inside or outside a maintenance building. The age of underground storage tanks is variable, ranging from new to 40 years old.

Figure 3 summarizes used oil management practices by automotive generators.

Most automotive oil generators are paid for their oil by a collector. Prices received vary widely and depend primarily on oil demand and collector competition in a given region. In 1983, 20¢/gal was a common price for good quality oil, with variations ranging from 0 to 45¢/gal.

3.4.2 Industrial Generators of Used Oil

Industrial and manufacturing establishments that routinely generate one or more types of used oil are classified as industrial generators. The generated oil may be recovered for reuse on-site or it may be collected and stored for pickup by a used oil collector or processor. Figure 4 summarizes used oil management practices by industrial generators.

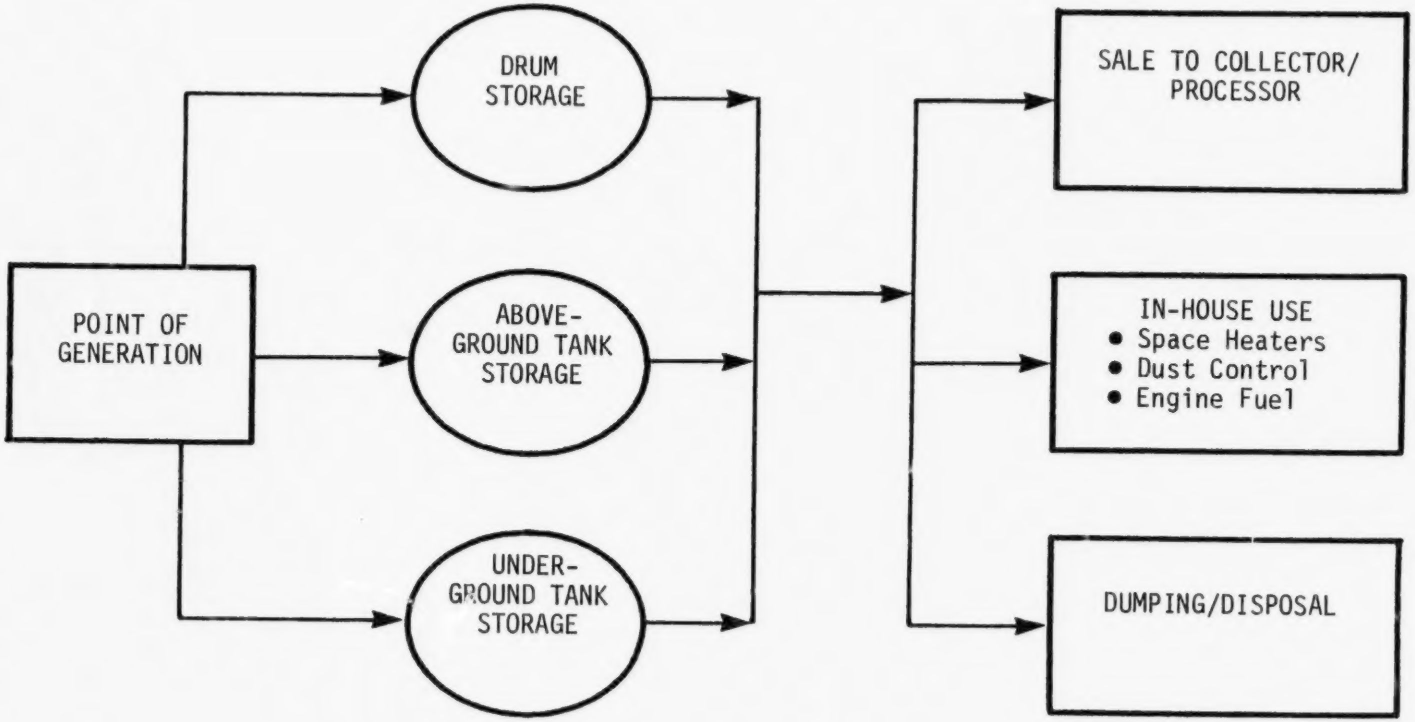
POINT OF GENERATION
DRUM STORAGE
ABOVE-GROUND TANK STORAGE
UNDER-GROUND TANK STORAGE
SALE TO COLLECTOR/ PROCESSOR
IN-HOUSE USE
• Space Heaters
• Dust Control
• Engine Fuel
DUMPING/DISPOSAL

Figure 3. Automotive generator used oil management practices.

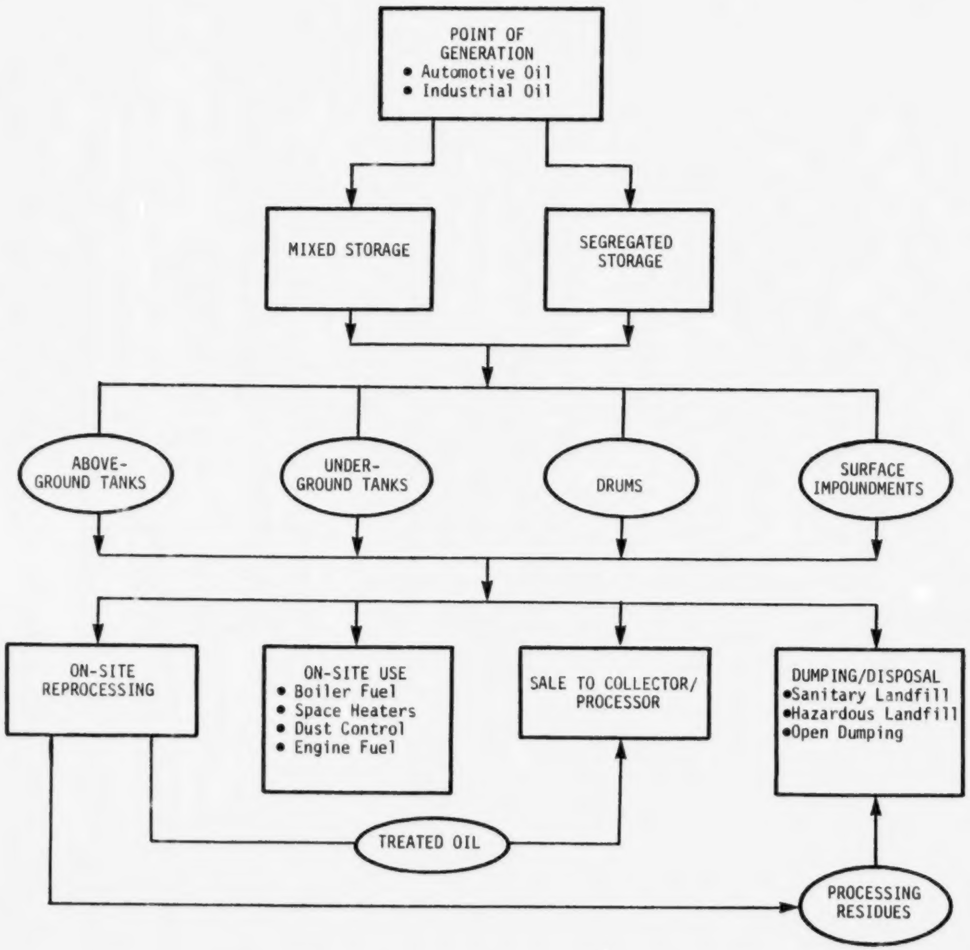
POINT OF GENERATION
• Automotive Oil
• Industrial Oil
MIXED STORAGE
SEGREGATED STORAGE
ABOVE-GROUND TANKS
UNDER-GROUND TANKS
DRUMS
SURFACE IMPOUNDMENTS
ON-SITE REPROCESSING
ON-SITE USE
• Boiler Fuel
• Space Heaters
• Dust Control
• Engine Fuel
SALE TO COLLECTOR/PROCESSOR
DUMPING/DISPOSAL
•Sanitary Landfill
•Hazardous Landfill
•Open Dumping
TREATED OIL
PROCESSING RESIDUES

Figure 4. Industrial generator used oil management practices.

There are three basic categories of used oil generated in industrial establishments. The oil categories include primarily straight mineral oils and lesser amounts of emulsified oils and synthetic oils. Many specific end-uses exist for industrial oils (see Table 13).

The relative amounts of the different oil types and end-uses varies based upon the specific manufacturing processes utilized by the industrial establishments. For example, a metalworking facility* may generate a significant amount of emulsified oils used in metal forming, metal removal, and heat treating processes, and a smaller amount of straight mineral oils from industrial lubricant applications and hydraulic systems. Other companies may generate only straight mineral oils from hydraulic systems and automotive equipment.

Because of the diversity of industrial establishments, there are literally hundreds of combinations of oil types which may be available to a collector. In some cases automotive oil may be mixed with accumulated industrial oils, but this is only common when small quantities of one or both types are generated. When a large quantity of any given oil type is generated on-site, segregation is common. Some non-oil materials, such as solvents, are sometimes mixed with oil at industrial establishments. Used oil storage containers often serve as a "catch-all" for any liquid waste generated on-site. This contamination is examined further in Section 3.4.3.

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* Metalworking facilities comprise the largest single group of industrial establishments in the United States with over 100,000 individual plants (SICs 25, 33, to 39). Also, this industry segment is a major consumer of oils (150-200 million gallons annually) (17).

An industrial facility may generate anywhere from under a hundred to over one hundred thousand gallons of used oil per year. Including oil emulsions, some facilities generate over a million gallons per year. Typical generation rates for straight mineral oils seldom exceed a few thousand gallons per year.

Only a small fraction of industrial facilities have oil inventory programs to account for oil purchases, recovery, and sales. One published report indicates that most industrial facilities cannot account for up to 50 percent of their oil purchases (17). Losses can be attributed to sloppy accountability methods and actual losses down drains, miscellaneous spills, oil on cloth and paper wipes, and oil included in final products.

Industrial used oil generators may do one of three things with the waste oil accumulated on their plant site. They may (1) treat the oil on-site for reuse; (2) transfer all the oily material to an independent collector for processing and/or disposal; or (3) perform some on-site treatment to improve the quality and then transfer the valuable materials to an independent collector. Each of these three management methods is commonly practiced.

On-site handling of used oils may be very simple or quite sophisticated for industrial establishments. Storage of straight mineral oils is in 55-gallon drums or in above or below ground steel tanks ranging from 500 to 10,000 gallons. If emulsified oils are generated, storage requirements may be much larger. Both tanks and surface impoundments are used to store large volumes of emulsified oils by industrial generators. Tanks are generally above-ground and may be open-topped. Impoundments range widely in size and serve as treatment and disposal alternatives for oil emulsions as well as storage devices.

Most used industrial oils are collected as part of the used oil management system. Only about 9 percent are reclaimed in-house for reuse. An additional 7 percent is used as a fuel supplement; 15 percent is disposed or incinerated by the generator; and less than 1.0 percent is used to suppress dust (5).

The price which the generator receives for used industrial oil varies from 0 to 40¢/gallon (5). In some cases, generators must pay collectors to haul low quality oils off their premises.

3.4.3 Used Oil Composition According to Source

About 40 percent of the 1,071 analyzed used oil samples could be classified according to source; that is, automotive or industrial. The remaining 60 percent were either unidentified or classified as mixed oils. This section summarizes the contamination of potentially hazardous constituents in used oils according to source. General summaries are included for automotive, industrial, and "unknown source" oils, and further detail is provided to break these categories down into more specific oil types where the data are available.

The presence of 20 potentially hazardous constituents and total chlorine in automotive, industrial, and "unknown source" oils are summarized in Tables 15, 16, and 17, respectively. A full statistical summary which includes the number of analyzed samples, contaminant detection frequency, and contaminant concentration according to mean, median, 75th and 90th percentile, and range is presented for each source category. Table 18 compares the mean, median, and 90th percentile concentration of these constituents by

Table 15

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN USED AUTOMOTIVE OIL SAMPLES

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	75	16	21	14.3	5	5	13.95	0.4	26
Barium	171	163	95	184.0	82.5	175	428	0.78	3,906
Cadmium	115	91	79	2.0	1.4	3	6.5	<0.2	10
Chromium	153	144	94	11.5	7	11	22	0.3	126
Lead	96	94	97	1,603.1	900	1,600	2,300	1	21,700
Zinc	175	174	99	870.1	917.5	1,100	1,251	4.4	3,000
Chlorinated Solvents									
Dichlorodifluoromethane	7			NO DETECTED LEVELS					
Trichlorotrifluoroethane	7	1	14	530	20	20	20	<20	530
1,1,1-Trichloroethane	73	41	56	3,313.3	82	860	3,000	<1	36,000
Trichloroethylene	71	15	21	1,436.2	16	100	220	<1	6,100
Tetrachloroethylene	71	31	43	2,990.9	20	185	900	<1	24,400
Total Chlorine	90	89	98	3,600	1,100	2,000	8,500	<100	47,200
Other Organics									
Benzene	56	35	62	430.4	73	190	330	<1	3,600
Toluene	56	50	89	2,076.4	710	1,900	5,100	<1	12,000
Xylenes	53	50	94	1,664.3	710	1,600	3,200	<2	14,000
Benzo(a)anthracene	8	6	75	19.3	10	20	20	<10	40
Benzo(a)pyrene	29	21	72	9.7	10	12	14	<1	17
Naphthalene	8	8	100	377.5	280	490	560	170	580
PCBs	74	3	4	20.7	5	5	10	<0.1	50

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

Table 16

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN USED INDUSTRIAL OIL

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	98	7	7	7.9	5	5	5	0.01	21
Barium	148	136	91	107.8	32	116	240	0	1,100
Cadmium	163	68	41	6.1	3	7	10	0	40
Chromium	157	130	82	36.8	5	12	45	0	571
Lead	171	148	86	217.7	24	114	330	0	3,500
Zinc	168	165	98	373.3	86	330	650	0.5	8,610
Chlorinated Solvents									
Dichlorodifluoromethane					NOT MEASURED				
Trichlorotrifluoroethane	2	2	100	200,000	-	-	-	100,000	300,000
1,1,1-Trichloroethane	92	38	41	3,416.3	100	800	2,600	2	62,000
Trichloroethylene	94	31	32	1,725.6	100	200	430	2	26,000
Tetrachloroethylene	93	40	43	1,453.6	100	710	1,500	2	7,700
Total Chlorine	105	98	93	6,100	2,000	6,100	12,000	<100	86,700
Other Organics									
Benzene	40	5	12	3,606	15	16	100	2	8,200
Toluene	41	21	51	2,226	16	170	1,800	2	18,000
Xylenes	41	23	56	1,046.06	26	590	1,200	2	5,100
Benzo(a)anthracene					NOT MEASURED				
Benzo(a)pyrene					NOT MEASURED				
Naphthalene					NOT MEASURED				
PCBs	94	6	6	957.2	10	10	50	<0.5	3,800

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

Table 17

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN USED OIL SAMPLES FROM MIXED OR UNKNOWN SOURCES

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	364	112	30	18.3	5	7.4	20	0.9	100
Barium	433	376	86	118.1	40	108	210	0	1,710
Cadmium	466	112	24	2.4	7	10	10	<0.2	57
Lead	568	518	91	621.8	321	740	1,100	0	19,000
Chromium	466	318	71	31.9	7	12	42	0	690
Zinc	468	461	98	546.3	490	789	1,050	1	3,800
Chlorinated Solvents									
Dichlorodifluoromethane	80	51	63	373.3	20	180	860	<1	2,200
Trichlorotrifluoroethane	19	14	73	47,812.9	230	1,300	1,900	28	550,000
1,1,1-Trichloroethane	453	309	68	2,630.1	300	1,400	3,400	<2	110,000
Trichloroethylene	19	12	63	1,197.5	100	740	1,600	0	4,900
Tetrachloroethylene	436	280	64	1,236.8	170	610	1,500	<1	32,000
Total Chlorine	395	381	96	3,624.3	1,900	4,600	18,000	<100	459,000
Other Organics									
Benzene	142	78	54	1,029.8	30	110	250	<1	55,000
Toluene	147	129	87	2,259.6	450	1,300	4,400	<2	55,000
Xylenes	143	122	85	4,506.1	600	1,400	3,000	<1	139,000
Naphthalene	17	17	100	521.2	330	750	998	110	1,400
Benzo(a)anthracene	19	14	73	93.6	12	30	60	5	660
Benzo(a)pyrene	36	17	47	43.0	10	12	16	1	405
PCBs	586	133	22	72.2	6	15	50	0	3,150

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

Table 18

COMPARISON OF CONTAMINANT CONCENTRATIONS BY OIL SOURCE

	Automotive Oil			Industrial Oil			Unknown Source		
	Mean concentration* (ppm)	Median concentration (ppm)	Concentration at 90th percentile (ppm)	Mean concentration* (ppm)	Median concentration (ppm)	Concentration at 90th percentile (ppm)	Mean concentration* (ppm)	Median concentration (ppm)	Concentration at 90th percentile (ppm)
Metals									
Arsenic	14.3	<5	14.0	7.9	<5	<5	18.3	<5	20
Barium	184	82	428	108	32	240	118	40	210
Cadmium	2.0	1.4	6.5	6.1	3	10	2.4	7	10
Chromium	11.5	7	22	36.8	5	45	31.9	7	42
Lead	1,603	900	2,300	218	24	330	622	321	1,100
Zinc	870	918	1,251	373	86	650	546	490	1,050
Total Chlorine	3,600	1,100	8,500	6,100	2,000	12,000	3,624	1,900	18,000
Chlorinated Solvents									
Dichlorodifluoromethane	<20	<20	<20	-	-	-	373	20	860
Trichlorotrifluoroethane	530	<20	<20	-	-	-	47,813	230	1,900
1,1,1-Trichloroethane	3,313	82	3,000	3,416	100	2,600	2,630	300	3,400
Trichloroethylene	1,436	<16	220	1,726	100	430	1,198	100	1,600
Tetrachloroethylene	2,991	<20	900	1,454	100	1,500	1,237	170	1,500
Other Organics									
Benzene	430	73	330	3,606	15	100	1,030	30	250
Toluene	2,076	710	5,100	2,226	16	1,800	2,260	450	4,400
Xylene	1,664	710	3,200	1,046	26	1,200	4,506	600	3,000
Benzo(a)anthracene	19.3	10	20	-	-	-	521	330	998
Benzo(a)pyrene	9.7	10	14	-	-	-	94	12	60
Naphthalene	337	280	560	-	-	-	43	10	16
PCBs	20.7†	5	10	957‡	10	50	72	6	50

* Calculated for detected concentrations only.

† Only 3 out of 74 samples contained measurable PCBs. It is likely that these oils were not strictly automotive oil.

‡ Only 6 out of 94 samples contained measurable PCBs with one very high concentration (3,800 ppm).

Source: Appendix A data.

source of oil. Since a discussion of overall used oil contamination was presented earlier (Section 1.4 - Overview), the discussion in this section is limited to the differences which have been measured in automotive and industrial oils.

In general, used automotive oils have higher concentrations of the metals than industrial oils, but similar solvent concentrations. One exception is slightly higher cadmium levels in industrial oils. No significant differences were noted in the concentrations of the other organics and arsenic. Despite any relative differences in concentrations according to source, the data in Table 18 show that high levels of many hazardous constituents have been found in both automotive and industrial oils.

According to the used oil collectors and processors, industrial oils are more likely to be contaminated with PCBs than are automotive oils; however, data are insufficient to verify this. The presence of PCBs in used oil depends on the source of the oil and the material and containers it comes into contact with during handling. Automotive oils are generally free of PCBs; however, until the early 1970s, small amounts of PCBs were added to certain automobile transmission fluids to enhance controlled swelling of rubber seals. These fluids can contribute low levels of PCB contamination to automotive oils. Industrial oils may be contaminated by old hydraulic and electrical oils which contained PCBs.* When manufacture of PCB-containing hydraulic fluids was discontinued, it was recommended that hydraulic systems not be drained, flushed, or refilled. Instead, the public was advised to replace these fluids with non-PCB-containing hydraulic fluids as leaks and spills occurred. As a result, PCB levels in many hydraulic systems can still range from 60 to 500,000 ppm.

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* Collectors, processors, and re-refiners indicate that industrial oils commonly have PCBs concentrations of 5 to 10 ppm.

Until 1977, electrical oils, which were used as a dielectric fluid in transformers and other electrical equipment, contained PCBs. Many transformer systems still contain PCBs. The preamble to EPA's PCB regulations states that as many as 38 percent of the 35 million transformers using mineral oil contain between 50 and 500 ppm PCBs. An independent testing laboratory estimates that about 50 percent of all transformer oils are contaminated with PCB in concentrations greater than 50 ppm. This occurs because, even if transformers are drained and cleaned out, PCBs are likely to remain in the system.

3.4.3.1 Effect of Sampling on Contaminant Concentrations

In Tables 15 and 16, the analytical results were summarized according to whether the samples were identified as automotive or industrial. However, some of those samples were taken directly from generators while others were taken from collectors or processors who identified the samples. There was some question whether samples obtained from collectors or processors were strictly the types of oil which they reported or whether they may have had some other oil or waste material mixed into them. In an attempt to assess this possibility, the automotive and industrial samples were split into those obtained directly from generators and those obtained from collectors or processors. The results are summarized in Tables 19 and 20 for automotive oils and Tables 21 and 22 for industrial oils.

Some interesting observations can be made from this analysis. Overall, most metals concentrations in automotive oils are higher when the samples were taken directly from generators and the chlorinated solvent

Table 19

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN AUTOMOTIVE USED OIL SAMPLES TAKEN DIRECTLY FROM GENERATORS

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	24	2	8	9.92	5	5	5	<5	13.95
Barium	113	108	95	209.5	94.3	200	428	0.78	3,906
Cadmium	64	60	93	1.7	1.3	2	4.1	<0.2	10
Chromium	99	97	97	10.8	8	12	21.3	0.5	50
Lead	40	39	97	2,573.7	1,470	2,210	3,300	5	21,700
Zinc	116	116	100	982.3	1,000	1,151	1,316	4.4	3,000
Chlorinated Solvents									
Dichloridifluoromethane				NOT MEASURED					
Trichlorotrifluoroethane				NOT MEASURED					
1,1,1-Trichloroethane	22	4	18	401.3	6	11	16	<1	1,000
Trichloroethylene	22	2	9	2.5	5	8	11	<1	16
Tetrachloroethylene	22	8	36	180.1	8.6	15	55	<2	660
Total Chlorine	36	36	100	1,200.0	800	1,400	2,000	<100	4,700
Other Organics									
Benzene	22	10	45	589.0	9	60	130	1	3,600
Toluene	22	19	86	1,010.7	190	670	1,500	1	6,500
Xylene	22	20	90	2,005.2	490	1,200	1,900	2	14,000
Benzo(a)anthracene				NOT MEASURED					
Benzo(a)pyrene	21	21	100	9.7	10	14	14	1.3	17
Naphthalene				NOT MEASURED					
PCBs	22	1	5	39	-	-	-	-	-

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

Table 20

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN USED AUTOMOTIVE OIL SAMPLES TAKEN FROM COLLECTORS OR PROCESSORS

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	52	14	26	15.0	5	5	17	0.4	26
Barium	58	55	94	133.9	31	62	284	2	1,631
Cadmium	51	31	60	2.0	1.6	5	7	0.5	10
Lead	56	55	98	914.8	730	1,100	1,417	1	11,000
Chromium	53	46	86	12.9	4.5	6.3	25	0.3	126
Zinc	59	58	98	645.9	660	920	1,100	5	1,550
Chlorinated Solvents									
Dichlorodifluoromethane	7				NO DETECTED LEVELS				
Trichlorotrifluoroethane	7	1	14	530	20	20	20	<20	530
1,1,1-Trichloroethane	50	36	72	3,728.8	160	1,600	6,000	<7	36,000
Trichloroethylene	49	13	26	1,656.8	20	100	800	<1	6,100
Tetrachloroethylene	49	23	46	3,968.6	83	300	3,000	<1	24,000
Total Chlorine	54	53	98	5,300	1,200	3,200	12,200	<100	47,200
Other Organics									
Benzene	34	25	73	367.0	100	220	330	<4	2,500
Toluene	34	31	91	2,729.5	1,200	2,300	7,400	<7	12,000
Xylenes	31	30	96	1,437.1	960	1,700	2,400	<3	6,700
Naphthalene	8	8	100	377.5	280	490	560	170	580
Benzo(a)anthracene	8	6	75	19.3	10	20	20	10	40
Benzo(a)pyrene	8				NO DETECTED LEVELS				
PCBs	50	3	6	20.7	5	10	10	<1	50

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

Table 21

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN USED INDUSTRIAL OIL SAMPLES TAKEN FROM GENERATORS

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	27			NO DETECTED LEVELS					
Barium	54	51	94	46.77	13	45	100	<0.5	330
Cadmium	70	44	62	3.35	0.5	2.6	5	0	21
Chromium	76	62	81	14.63	2.4	7	15	0	520
Lead	77	66	85	278.46	15	56	290	0	3,500
Zinc	74	73	98	149.12	39	190	330	<0.5	1,200
Chlorinated Solvents									
Dichlorodifluoromethane				NOT MEASURED					
Trichlorotrifluoroethane	2	2	100	200,000	100,000	100,000	100,000	100,000	300,000
1,1,1-Trichloroethane	27	1	3	62,000	15	16	33	<2	62,000
Trichloroethylene	28	3	10	21.43	15	16	33	<3	70
Tetrachloroethylene	27	3	11	510.73	15	16	60	<2.2	1,300
Total Chlorine	31	26	83	10,500	500	3,200	9,600	<100	87,700
Other Organics									
Benzene	27	4	14	4,482.5	15	16	130	<2	8,200
Toluene	28	15	53	2,685.8	16	630	4,800	<4	18,000
Xylenes	28	18	64	1,201.64	28	1,100	1,600	<3	5,100
Benzo(a)anthracene				NOT MEASURED					
Benzo(a)pyrene				NOT MEASURED					
Naphthalene				NOT MEASURED					
PCBs	28	4	14	485.57	5	5	11	<0.5	1,900

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

Table 22

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN USED INDUSTRIAL OIL SAMPLES TAKEN FROM COLLECTORS AND PROCESSORS

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	71	7	9	7.85	5	5	5	<2	21
Barium	94	85	90	144.37	55	160	379	0	1,100
Cadmium	93	24	25	11.09	5	7	10	0	40
Chromium	81	68	83	56.92	8	25	107	<0.5	571
Lead	94	82	87	168.81	32	156	350	<0.5	2,000
Zinc	94	92	97	551.12	170	450	831	<1	8,610
Chlorinated Solvents									
Dichlorodifluoromethane				NOT MEASURED					
Trichlorotrifluoroethane				NOT MEASURED					
1,1,1-Trichloroethane	65	37	56	1,832.97	200	1,200	3,500	<2	8,400
Trichloroethylene	66	28	42	1,908.14	100	220	600	<2	26,000
Tetrachloroethylene	66	37	56	1,530	200	990	2,200	<2	7,700
Total Chlorine	74	72	97	4,600	2,600	6,400	11,400	<100	16,700
Other Organics									
Benzene	13	1	7	100	14	16	20	<2	100
Toluene	13	6	46	1,076.5	16	57	230	<2	5,700
Xylenes	13	5	38	486	16	140	560	<2	700
Benzo(a)anthracene				NOT MEASURED					
Benzo(a)pyrene				NOT MEASURED					
Naphthalene				NOT MEASURED					
PCBs	66	2	3	1,900.32	10	50	50	<0.65	3,800

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

concentrations are lower. Differences in the levels of other organics cannot be determined from the data. These conditions may indicate that some industrial oils could have been mixed into the used oils identified as automotive by collectors and processors, because industrial oils generally tend to have lower levels of some metals, but higher levels of chlorinated solvents.

The levels of metals and chlorinated organics detected in industrial samples taken directly from generators are quite a bit below the levels measured in samples received from collectors and processors.

Overall, it appears that the collectors and processors tend to mix contaminating material into used oils which decreases quality to some extent. Better segregation practices and material selectiveness could improve the quality of oil received by processing facilities and ultimately reused.

3.4.3.2 Contamination of Gasoline Versus Diesel Engine Oils

Most of the automotive oil samples were obtained from gasoline burning engines. Only eight analysis results of diesel engine oil were obtained. However, from these limited data, there appears to be some distinct differences in the two oils with respect to the presence of potentially hazardous metals. Table 22a compares the metals concentrations in gasoline and diesel engine oils. As expected, the lead concentration in the gasoline engine oils is much higher than in diesel engine oils. This difference is diminishing due to the shift away from leaded gasolines. Gasoline engine oils also appear to have higher concentrations of the other metals than the diesel oils; however, the data are too limited for the diesel samples to be conclusive.

Table 22a

CONCENTRATION OF POTENTIALLY HAZARDOUS METALS IN GASOLINE AND DIESEL ENGINE OILS†

	Total samples analyzed	Samples with detected contaminant		Mean concentration* (ppm)	Median concentration (ppm)	Concentration range (ppm)	
		number	percent			low	high
Metals							
Arsenic							
Diesel	5	1	20	5.9	<5	<5	5.9
Gasoline	44	7	16	13	<5	<0.4	17
Barium							
Diesel	5	5	100	6.8	4.1	0.78	19
Gasoline	138	133	96	207	87	2	3,906
Cadmium							
Diesel	5	3	60	1.1	0.88	<0.5	1.4
Gasoline	86	82	95	1.7	1.3	0	8.8
Chromium							
Diesel	5	5	100	2.0	1.5	0.86	3.8
Gasoline	123	121	98	9.7	7.7	0.3	50
Lead							
Diesel	5	4	80	29	13	<5	78
Gasoline	87	87	100	2,232	390	8.5	21,676
Zinc							
Diesel	5	5	100	332	280	4.4	820
Gasoline	142	142	100	951	990	6	3,000

* Calculated for samples with detected concentrations only.

† Although reported as diesel engine oils, some of these samples are believed to contain some gasoline engine oils.

Source: Appendix A data.

Table 23 compares the concentration of some potentially hazardous organics in used gasoline and diesel engine oils. As with the metals, more data are available for gasoline engines than for diesel engine oils. Since the data are very limited, few conclusions can be drawn. It does appear that benzo(a)pyrene (a carcinogen) is present at higher levels in the gasoline engine oils.

Table 23

CONCENTRATION OF POTENTIALLY HAZARDOUS ORGANIC CONSTITUENTS IN GASOLINE AND DIESEL ENGINE OILS

Contaminant	Concentration diesel*	Mean concentration gasoline†
1,1,1-Trichloroethane	200, 200	445
Trichloroethylene	2,660	84
Tetrachloroethylene	293	453
Benzene	21	92
Toluene	1,960	1,374
Xylene	1,817	1,289
Benzo(a)pyrene	1.3, 1.5, 1.3, 1.7	11.7

* All available data are shown.

† Number of samples detecting contaminant range from 4 to 18 for these constituents.

Source: Appendix A data.

Overall, diesel engine oils are less contaminated by potentially hazardous constituents than gasoline burning engine oils.

3.4.3.3 Contamination of Specific Industrial Oils

There are many specific types of used industrial oils each with its own characteristics regarding the presence of potentially hazardous constituents.

In many cases, the industrial used oil samples were identified according to their specific types. Tables 24 to 26 summarize the concentration of potentially hazardous constituents in three general types of used industrail oils: (1) metalworking oils;* (2) cooling oils; and (3) hydraulic oils. Overall, the metals concentrations are highest in the metalworking oils, particularly lead and chromium concentrations. Fairly high levels of total chlorine (up to 8 percent by weight) have been measured in metalworking and hydraulic oils. This chlorine is likely to be present as a result of mixing solvents with used oils. Cooling and hydraulic oils have relatively low levels of metals and other contaminants compared to metalworking oils. The presence of at least low levels of chlorinated solvents and PCBs in these oils indicates that industrial generators do have a tendency to mix other materials with their used oils.

3.4.3.4 Presence of Priority Pollutants by Oil Type

Thus far in this section, used oil contamination has been described with respect to eighteen specific frequently detected hazardous constituents and total chlorine. There are, however, many other hazardous pollutants which may be inherently found in used oil or perhaps mixed into oil as a part of its management. To assess the presence of other pollutants, EPA commissioned a study to thoroughly analyze 50 methodically selected used oil samples for priority pollutants. Some of the contaminants previously discussed are also included in the comprehensive GC/MS analysis for priority pollutants.

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* Straight mineral oil metalworking fluids used in iron and steel fabrication processes such as cutting, machining, stamping, and drawing.

Table 24

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN USED CUTTING OR MACHINE OILS

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	12			NO DETECTED LEVELS					
Barium	29	28	96	65.84	23	93	120	<0.5	330
Cadmium	39	23	58	3.69	0.5	1	5	0	21
Chromium	39	30	76	24.23	2	6.7	15	0	520
Lead	40	36	89	210.14	16	84	170	<0.01	3,500
Zinc	41	41	100	80.99	38	123	200	0.53	530
Chlorinated Solvents									
Dichlorodifluoromethane				NOT MEASURED					
Trichlorotrifluoroethane	2	2	100	200,000	100,000	100,000	100,000	100,000	300,000
1,1,1-Trichloroethane	12			NO DETECTED LEVELS					
Trichloroethylene	14	3	21	8,685.36	15	16	20	<4.1	26,000
Tetrachloroethylene	13	3	23	1,234.06	15	16	20	<2.2	2,400
Total Chlorine	14	11	78	24,000	4,000	9,600	54,500	<100	86,700
Other Organics									
Benzene	12			NO DETECTED LEVELS					
Toluene	14	5	35	1,550.22	15	16	230	<7	5,700
Xylenes	14	10	71	488.66	70	560	660	<7	1,100
Benzo(a)anthracene				NOT MEASURED					
Benzo(a)pyrene				NOT MEASURED					
Naphthalene				NOT MEASURED					
PCBs	13	4	30	1,432.82	5	7	50	<5	3,800

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

Table 25

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN USED COOLING OILS

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	3			NO DETECTED LEVELS					
Barium	3	3	100	11.93	7.8	14	14	7.8	14
Cadmium	4			NO DETECTED LEVELS					
Chromium	4	3	75	1.73	1.5	1.5	1.5	<0.01	2.2
Lead	4	4	100	171.25	44	290	290	21	330
Zinc	4	4	100	5.47	2.3	3.7	3.7	1.9	14
Chlorinated Solvents									
Dichlorodifluoromethane				NOT MEASURED					
Trichlorotrifluoromethane				NOT MEASURED					
1,1,1-Trichloroethane	3			NO DETECTED LEVELS					
Trichloroethylene	3			NO DETECTED LEVELS					
Tetrachloroethylene	3			NO DETECTED LEVELS					
Total Chlorine	3	1	33	700	100	100	100	<100	700
Other Organics									
Benzene	3			NO DETECTED LEVELS					
Toluene	3			NO DETECTED LEVELS					
Xylenes	3			NO DETECTED LEVELS					
Benzo(a)anthracene				NOT MEASURED					
Benzo(a)pyrene				NOT MEASURED					
Naphthalene				NOT MEASURED					
PCBs	3			NO DETECTED LEVELS					

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

Table 26

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN USED HYDRAULIC OILS

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	8			NO DETECTED LEVELS					
Barium	9	7	77	15.96	3.1	5	26	<0.5	56
Cadmium	10	6	60	1.66	0.5	1.1	2.5	<0.5	4
Chromium	10	6	60	1.17	0.5	0.59	2.1	<0.1	3
Lead	10	4	40	71.15	5	5	130	<0.6	150
Zinc	10	9	90	189.83	17	210	400	<0.5	600
Chlorinated Solvents									
Dichlorodifluoromethane				NOT MEASURED					
Trichlorotrifluoroethane				NOT MEASURED					
1,1,1-Trichloroethane	8	3	37	23,520	4	160	8,400	<2	62,000
Trichloroethylene	8	1	12	18	4	11	14	<2	18
Tetrachloroethylene	8	2	25	545	4	11	110	<2	980
Total Chlorine	8	8	100	5,600	200	7,500	8,000	100	24,600
Other Organics									
Benzene	8	1	12	100	4	11	14	<2	100
Toluene	8	5	62	1,366.19	9	170	310	<2	6,300
Xylenes	8	4	50	220.75	7	26	140	<2	700
Benzo(a)anthracene				NOT MEASURED					
Benzo(a)pyrene				NOT MEASURED					
Naphthalene				NOT MEASURED					
PCBs	8			NO DETECTED LEVELS					

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

The results of those analyses indicated that many priority pollutants were detected in each oil type. Tables 26a to 26f show all of the contaminants detected in each oil type and their concentrations. Table 26g was prepared to simplify this analysis and to better understand the frequency of detection of all acid and base/neutral compounds. The data in Table 26g illustrate a few major points. First, the major contaminants found in automotive oils are similar to those found in industrial oils and mixed oils. Overall, from these limited data, it seems that industrial hydraulic and metalworking oils have substantially lower levels of priority pollutants than automotive oil, but they appear nearly similar in Table 26g due to the inclusion of highly contaminated used oils from barge cleaning in the industrial category.

It is important to note that the detection levels for these pollutants was 50 ppm which is quite high with respect to previously obtained data. Previously presented results showed that benzo(a)pyrene concentrations range typically from <10 to 15 ppm. Similarly, other data (see Appendix A) show typical phenol concentrations of 10 to 40 ppm in used oils. Thus, the detection of these, and perhaps other compounds, may be very much understated due to a detection level of 50 ppm. The "trace" distinction in these analyses does not seem to significantly affect this observation (e.g., the percent B(a)P detection in mixed oils is zero even if trace levels are included).

For those base/neutral compounds which were frequently detected, a summary of concentration levels is shown in Table 26h. Separate summaries are shown for barge cleaning oils and other industrial oils because the analyzed barge cleaning oils were very contaminated and including them with

Table 26a

USED AUTOMOTIVE OIL
(ppm)

Contaminants	New Car Dealers	Service Stations	Repair/Maintenance Shops
Base/Neutral Compounds			
1,2-dichlorobenzene	116	-	168
fluoranthene	tr <50	tr <50, tr <50	tr <50
naphthalene	735, 149	755, 693	624, 542, [tr <50, tr <50] 2/, 788
benzo(a)anthracene	tr <50	53.8	-
chrysene	tr <50	tr <50	-
fluorene	tr <50, 61.8	tr <50, tr <50	tr <50, tr <50
phenanthrene	99.8, 121	69.5, 101	58.7, 53.2, [tr <50, tr <50], 2080
pyrene	84.3, tr <50	55.9, 75.9	tr <50, 50.3, [tr <50, tr <50], 68.5
2-methylnaphthalene	830, 312	1170, 851	565, 509, [61.4, 52.1], 1060
Other Compounds			
C3-benzene	(1460, 2080, 510) 1/	(1630, 670), (1440, 2100, 580)	1040, 680, 750
propenyl benzene	260	220	-
methyl propyl benzene	690	820	-
C4-benzene	(500, 440, 550)	(610, 420), (290, 380, 500)	390, 700, 900
methyl propenyl benzene	(400, 630)	620, (460, 740)	(340, 580), 1000, 1200
methyl naphthalene	360, 140	530, 370	270, 520
dimethyl naphthalene	(500, 480, 530)	(360, 510, 220)	250
trimethyl benzene	-	-	(1500, 2800), (2900, 1900)

1/ ( ) indicates more than one number reported for a given contaminant.
2/ [ ]: Sample #128 has 2 sets of data (128-1, 128-2).

Source: Southwest Research Institute analyses, under EPA contract submitted Summer 1984.

Table 26b

USED INDUSTRIAL OIL
(ppm)

Contaminants	Barge Cleaning	Hydraulic Oils	Metal Forming Oils
Acid Compounds			
phenol	325, 252	-	-
Base/Neutral Compounds			
acenaphthene	490, 275	-	-
fluoranthene	70, 88	-	-
naphthalene	2330, 2480	120, [tr <50, tr <50] 2/, tr <50	314, [tr <50, tr <50]
bis(2-ethylhexyl) phthalate	<100, <100	<100	<100
benzo(a)anthracene	170, 160	-	-
benzo(a)pyrene	150, 248	-	-
benzo(b)fluoranthene	92, 135	-	-
chrysene	340, 370	-	-
anthracene	230, 168	-	-
fluorene	530, 400	110	60, [51.0, 72.5]
phenanthrene	1140, 1070	170, [85, 100]	115, [60, 92.4]
pyrene	410, 470	tr <50	tr <50
dibenzofuran	148, 134	-	-
2-methylnaphthalene	2700, 2580	tr <50, [tr <50, tr <50]	56, [67.2, 111]
Other Compounds			
1,3,5,7-cyclooctatetraene	7400	-	-
trimethyl benzene/C10H22 alkane	4400	-	-
methyl naphthalene	2000, 1900	-	[64, 80]
dimethyl naphthalene	(3800, 430), (3780, 4300) 1/	-	-
methyl ethyl naphthalene	2200	-	-
methyl phenanthrene	1600	-	-
dimethyl benzene	(2900, 3200)	-	-
ethyl methyl benzene	2300	-	-
tetramethyl benzene	1500	-	-
benzene, 1,1'-ethylidene bis-	7100	-	-
cyclo hexanone, 2-cyclohexylide	4700	-	-
alkyl aromatic	5900	-	-
2,6-dibutyl methyl phenol	-	680	-

1/ ( ) indicates more than one number reported for a given contaminant.
2/ [ ]: Hydraulic Oils - Sample #92 has two sets of data (92, 92-2).
Metal Forming Oils - Sample #204 has two sets of data (204-1, 204-2).

Source: Southwest Research Institute analyses, under EPA contract submitted Summer 1984.

Table 26c

MIXED OIL FROM PROCESSORS

(ppm)

Contaminants	Receiving Tanks
Acid Compounds	
phenol	tr <50, tr <50
Base/Neutral Compounds	
acenaphthene	52.7, tr <50, tr <50
fluoranthene	tr <50, tr <50, tr <50, tr <50
naphthalene	445, 661, tr <50, 580, 300, 360
bis(2-ethyl hexyl) phthalate	555, 170, 190, <100
benzo(a)anthracene	tr <50
chrysene	54
fluorene	tr <50, 116, 130, 61, tr <50
phenanthrene	56.3, 214, 79, 220, 92, 60
pyrene	tr <50, tr <50, 75, tr <50, tr <50
dibenzofuran	tr <50, tr <50, tr <50
2-methylnaphthalene	535, 992, tr <50, 520, 250, 360
Other Compounds	
ethyldimethyl hexene	6170
unknown (scan 646, app M.W. 162)	5550
unknown (scan 639, app M.W. 162)	7940
unknown (scan 698, app M.W. 174)	890
diisopropyl benzene	(2990, 6520, 4520), (5470, 14300, 12000) 1/
pyrimidinone	7860
methyl naphthalene	280, 300
C3-benzene	(1700, 870), (160, 390)
methyl propenyl benzene	640
ethyl propenyl benzene	150
dimethyl naphthalene	(210, 250), (996, 1360, 1170), (740, 1350)
propyl benzene	730
trimethyl benzene	(4060, 1940, 4760, 1590), 2900
ethyl methyl benzene	1590
diethyl benzene	(1640, 850)
ethyl dimethyl benzene	1200
decanedioic acid, bis(2-ethyl hexyl) ester	2500
diethylene glycol	500
alkane	390
2,5,8,11,14-pentaoxapentadecane)	7000
C4-benzene	1070

1/ ( ) indicates more than one number reported for a given contaminant.

Source: Southwest Research Institute analyses, under EPA contract submitted Summer 1984.

Table 26d

MIXED OIL FROM PROCESSORS

(ppm)

Contaminants	Product Oil Tanks
Acid Compounds	
pentachlorophenol	tr <50
Base/Neutral Compounds	
acenaphthene	142, tr <50, tr <50, tr <50
fluoranthene	tr <50, tr <50, tr <50, tr <50, tr <50
naphthalene	403, 1660, 272, 321, 395, 359, 180
bis(2-ethyl hexyl) phthalate	1780, 798, 104, <100
di-n-butyl phthalate	132, 532
benzo(a)anthracene	tr <50, tr <50
chrysene	tr <50, tr <50
fluorene	85.7, 319, tr <50, 73.7, 91.3, tr <50, tr <50
phenanthrene	124, 609, tr <50, 99.7, 158, 202, 90, 70
pyrene	58.5, tr <50, tr <50, 58.3, tr <50, tr <50
dibenzofuran	138, tr <50, tr <50, tr <50
2-methylnaphthalene	802, 3190, 2140, 686, 767, 415, 210
Other Compounds	
methyl naphthalene	430, 430
dimethyl naphthalene	(650, 960) 1/, 350
C3-naphthalene	370
2,6-dibutyl methyl phenol	64, 300
acetic acid butyl ester	4530
decane	1190
C3-benzene	(590, 280)
C4-benzene	240
benzene, 1-methyl-2-(2-propenyl)	320
methyl ethyl naphthalene	140
ethyldimethyl hexene	1380
methylhexanoate	1930
methyl nonanoate	3120
nonoic acid	19500
methyl decanoate	1370
decanoic acid	9030
pentaoxapentadecane	2250
trimethyl phenol	1200
trimethyl benzene	850

1/ ( ) indicates more than one number reported for a given contaminant.

Source: Southwest Research Institute analyses, under EPA contract submitted Summer 1984.

Table 26e

MIXED OIL FROM PROCESSORS
(ppm)

Contaminants	Holding Tanks
Acid Compounds	
p-chloro-m-cresol	1630
pentachlorophenol	351
phenol	54
Base/Neutral Compounds	
1,2,4-trichlorobenzene	119
fluoranthene	tr <50, tr <50, tr <50
naphthalene	98, 448, 698, 413, 174, 326, 126, 772, 200
bis(2-ethylhexyl) phthalate	533, <100
fluorene	tr <50, 190, 103, 67.7, tr <50, tr <50, 52.3, 194, tr <50
phenanthrene	58.4, 223, 152, 94.7, 99.7, 50.2, 92.1, 313, tr <50
pyrene	tr <50, tr <50, tr <50, tr <50, tr <50, tr <50, tr <50, tr <50
dibenzofuran	179
2-methylnaphthalene	tr <50, 1080, 772, 538, 122, 245, 376, 2080, 210
Other Compounds	
methyl naphthalene	440, 600, 260, 150, 230, 440
C3-benzene	(750, 1400, 510), (2400, 1400), (1500, 680), 360, (1900, 1100) 1/
dimethyl naphthalene	(1200, 1900), (530, 630), (280, 420), (200, 350), (1400, 510)
C4-benzene	1400
benzene, 1-1'-ethylidene bis-	55
unidentified amine	640
cylohexanone	5470
ethyl cyclopentene	1050
cyclohexanol	2490
diisopropyl benzene	(2200, 13900)
methyl propenyl benzene	600
alkyl cyclohexane	(280, 1300)
cyclic hydrocarbon (unid.)	350
trimethyl benzene	750, 1500

1/ ( ) indicates more than one number reported for a given contaminant.

Source: Southwest Research Institute analyses, under EPA contract submitted Summer 1984.

Table 26f

MIXED OIL FROM PROCESSORS
(ppm)

Contaminant	Surface Impoundments
Base/Neutral Compounds	
acenaphthene	407
fluoranthene	tr <50
naphthalene	2550
bis(2-ethylhexyl) phthalate	2530
anthracene	81.3
fluorene	464
phenanthrene	416
pyrene	tr <50
dibenzofuran	1110
2-methylnaphthalene	3710
Other Compounds	
methyl propenyl benzene	5300
C5-benzene	2000
methyl naphthalene	3400
dimethyl naphthalene	(5700, 6500, 5500) 1/
C3-naphthalene	1800
2,6-dibutyl methyl phenol	1470
ethyl hexanoate	6560, 5970
unknown (scan 643 app M.W. 162)	5350
diisopropyl benzene	(3550, 6120, 4110)
unknown (scan 642 app M.W. 162)	5420

1/ ( ) indicates more than one number reported for a given contaminant.

Source: Southwest Research Institute analyses, under EPA contract submitted Summer 1984.

Table 26g

COMPARISON OF THE DETECTION OF SOME PRIORITY POLLUTANTS IN AUTOMOTIVE, INDUSTRIAL, AND MIXED USED OILS

	Automotive Oils			Industrial Oils			Mixed Oils		
	Number Tested	Number Detected	Percent Detection	Number Tested	Number Detected	Percent Detection	Number Tested	Number Detected	Percent Detection
Acid Compounds									
p-chloro-m-cresol	8	0	0	7	0	0	34	1	3
pentachlorophenol	8	0	0	7	0	0	34	1 (2)	3
phenol	8	0	0	7	2	29	34	1 (3)	3
Base/Neutral Compunds									
acenaphthene	8	0	0	7	2	29	34	2 (7)	6
fluoranthene	8	(4) [1]	0	7	2	29	34	(13)	0
naphthalene	8	7 (8)	88	7	4 (7)	57	34	22 (23)	65
bis(2-ethylhexyl) phthalate	8	0	0	7	(4)	0	34	8 (11)	24
benzo(a)anthracene	8	1	13	7	2	29	34	(3)	0
benzo(a)pyrene	8	0	0	7	2	29	34	0	0
benzo(b)fluoranthene	8	0	0	7	2	29	34	0	0
chrysene	8	(2)	0	7	2	29	34	1 (3)	3
anthracene	8	0	0	7	2	29	34	1	3
fluorene	8	1 (6)	13	7	5	71	34	13 (22)	38
phenanthrene	8	7 (8)	88	7	6	86	34	22 (24)	65
pyrene	8	5 (8)	63	7	2 (4)	29	34	3 (20)	9
dibenzofuran	8	0	0	7	2	29	34	3 (9)	9
2-methylnaphthalene	8	8	100	7	4 (6)	57	34	21 (23)	62
1,2-dichlorobenzene	8	2	25	7	0	0	34	0	0
di-n-butyl phthalate	8	0	0	7	0	0	34	2	6
1,2,4-trichlorobenzene	8	0	0	7	0	0	34	1	3

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[1] Values in parentheses indicate "trace" amount detected; these samples are not included in percent detection calculations.

Source: Tables 26a to 26f.

Table 26h

CONCENTRATIONS OF SOME FREQUENTLY DETECTED BASE/NEUTRAL COMPOUNDS

	Automotive Oil		Industrial Oil				Mixed Oil	
			Barge Cleaning		Other Industrial			
	Mean 1/	Range	Mean 1/	Range	Mean 1/	Range	Mean 1/	Range
Naphthalene	612	Tr 2/ to 788	2,405	2,330 to 2,480	217	Tr to 314	533	Tr to 2,550
Penanthrene	369	Tr to 2,080	1,105	1,070 to 1,140	114	76 to 170	162	Tr to 609
Pyrene	67	Tr to 84	440	410 to 470	ND 4/	-	64	Tr to 75
Fluorene	62 3/	Tr to 62	465	400 to 530	77	60 to 110	150	Tr to 464
2-Methylnaphthalene	669	57 to 1,170	2,640	2,580 to 2,700	73	Tr to 89	952	Tr to 3,710

1/ Data shown for detected levels only. See Table 26g for the number of samples included in each category for each compound. When more than one value was reported for a given compound in a sample, the mean was used.

2/ Tr: Trace.

3/ Only one sample

4/ ND: Not Detected.

Source: Tables 26a to 26f.

the other industrial oils would greatly distort the results. These data show that typical hydraulic and metalworking oils have lower levels of these compounds than automotive or mixed oils. The mixed oils more closely resemble automotive oils than industrial oils.

Thus far, this discussion has examined base/neutral and acid compounds only. Approximately 50 "other" priority pollutants were detected in one or more oil samples. It is very difficult to draw any conclusions from data of this nature. As with acid and base/neutral compounds, industrial hydraulic and metalworking oils are clearly the least contaminated by these "other" priority pollutants. Automotive oils are contaminated primarily by gasoline compounds or their derivatives. Higher levels of many types of "other" compounds were measured in mixed oils than in automotive or industrial oils. This may indicate the possibility of contamination from other sources.

The only way to assess contamination by "other" compounds is to thoroughly review the data in Tables 26a to 26f because the data are insufficient to develop statistical summaries.

3.4.4 Physical Characteristics of Used Oils by Source

Some of the physical characteristics of waste oil that are important with respect to the dispersion of the oil and its contaminants into the environment include flash point, bottom sediment and water, water only, viscosity, and gravity (density). Table 27 shows that a wide range of values for each parameter indicating wide variations in the characteristics of specific waste oil samples. Some noteworthy observations can be made for each parameter.

Table 27

SUMMARY OF MISCELLANEOUS PHYSICAL CHARACTERISTICS OF WASTE OIL SAMPLES

	Number of samples	Range		Mean	Median
		Low	High		
Flash point, (°F)	289	62	555	210	-
Bottom sediment and water (%)	320	0	99	19	9
Water only (%)	36	0	67	11	5
Viscosity (CS at 100°F)*	70	1	513	71	47
API gravity (°API)†	48	13	80	28‡	27
Energy content (Btu/gal)	231	4,142	23,045	16,495	17,200

* CS = centistokes; viscosity is often reported in SUS units also with the conversion to centistokes equal to:

$$\text{Centistokes} = [(0.00226 \times \text{SUS}) - (1.95 \div \text{SUS})] \times 100$$

† API Gravity is a unit often used to illustrate the density of oil. It can be converted into specific gravity by means of the following equation:

$$\text{Specific Gravity} = 141.5 \div (131.5 + {}^\circ\text{API})$$

‡ The mean API Gravity of 28 is equal to a specific gravity of 0.89.

Source: Appendix A data and references.

3.4.4.1 Flash Point

Table 28 summarizes the measured flash points for 289 used oil samples.

The measured flash point ranges from 62 to 525°F compared to temperatures of about 300 to 400°F for virgin oil and unadulterated used oil. This shows that the contaminants present in the oil can greatly impact the characteristics of ignitability. According to Subpart C of Part 261 of 40 CFR,* a waste is hazardous if it "has a flash point less than 60°C (140°F)." Nearly 28 percent of the used oil samples had a measured flash point below 140°F. These low flash points are due to the presence of chlorinated and organic solvents and gasoline.

3.4.4.2 Bottom Sediment and Water (BS&W)

Most used oil samples contain some BS&W but usually less than 10 percent by volume (see Table 27). Samples containing more than 10 percent usually include some contamination from tank bottoms, emulsified oils, or washdown fluids.

3.4.4.3 Viscosity

Viscosity is a measure of the internal friction of a liquid, or its resistance to flow. The wide variation in values (1 to 513) does not mean that one material is 513 times more or less viscous than another; the relationship is not a linear one. A better way to understand these numbers is by comparison. Gasoline has a viscosity of 100°F equal to about 5 centistokes, whereas some heavy machine oils have viscosities that exceed 2,000 centistokes. Some waste oil samples are less viscous than gasoline, which probably indicates a high solvent content.

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* Criteria for Listing a Hazardous Waste.

Table 28

SUMMARY OF FLASHPOINT FOR USED OIL SAMPLES BY OIL SOURCE AND END-USE

	Total samples analyzed	Number of samples with flashpoint <140°F	Mean temperature* (°F)	Temperature Range (°F)	
				low	high
By Source of Oil:					
Crankcase oil	77	7	276	<70	440
Industrial oil	106	7	273	80	525
Unknown generator	311	66	146	60	450
All samples	289	80	210	60	525
By End-Use Application					
Road oiling	18	11	121	72	165
Burning	51	28	146	60	284
Re-refiner	34	10	271	<80	480
Unknown	113	31	230	62	525

* Calculated for detected flashpoints only.

Source: Appendix A data.

3.4.4.4 API Gravity

The API gravity, measured in °API, is a density parameter that can be converted to specific gravity by use of a conversion equation (Table 27). The scale in °API is more precise than the specific gravity scale, which will have fewer significant figures when reported as whole numbers. In this scale, the lower the value, the more dense the oil. For example, the low value of 13 represents an oil sample that was 0.98 times as dense as water, whereas the high value of 80 represents an oil sample only 0.67 times as dense as water.

3.4.4.5 Energy Content

The energy content of used oil samples is measured as Btu per pound. Pure lube oil typically has a Btu content somewhat higher than 20,000 Btu per pound (3). The Btu content of used oil samples ranges from 4,142 to 23, 045 Btu per pound (see Table 29). Most samples range between 15,000 and 19,000 Btu per pound due to the presence of water and inorganic solids which contaminate the oil.

3.4.5 Other Material Handled by Collectors and Processors

Most collectors and processors handle used oil only, but it is not unusual for a company to handle other materials as well. For example, some used oil collectors may service establishments with septic wastes or greases and fats. Also, some may collect solvents or tank bottoms while providing disposal and/or tank cleaning services.

The degree to which these materials are mixed with used oil by the collector is unknown, but believed to be minor compared to the total quantities

Table 29

ENERGY CONTENT OF USED OIL SAMPLES
(Btu/lb)

	Total samples analyzed	Mean	Median	75th Percentile	90th Percentile	Range	
						Low	High
Automotive	38	17,737	18,072	18,813	18,893	15,156	20,087
Industrial	30	16,164	18,000	20,323	20,719	6,690	20,863
Unknown	163	16,267	16,888	18,334	19,156	4,142	23,045
All Samples	231	16,495	17,200	18,587	19,350	4,142	23,045

Source: Appendix A references.

of used oil collected. Nevertheless, it does occur to some degree. Most processors who collect these materials keep them segregated in storage. Some may mix them with used oil at controlled ratios as a means of disposing of the waste material. Solvents are commonly mixed with used oil as a method of viscosity control as well as to dispose of the solvent.

Some used oil collectors and processors handle materials which are clearly hazardous in nature. Most of these facilities are licensed to collect, process, and/or transport hazardous wastes. Some risks exist for used oil contamination by the hazardous constituents unless care is taken to avoid problems. The risks primarily involve using the same trucks and storage tanks for used oil as the hazardous materials. Unless the tanks are always thoroughly cleaned, used oils can be contaminated by residues left from a previously stored hazardous waste.

Section 4

USED OIL COLLECTION AND PROCESSING

4.1 OVERVIEW

This section describes the used oil management system and the composition of used oil at collection and processing facilities. Each of the major company types which participate in used oil management are described with respect to processing technology, product oil distribution, and residue generation and management. The concentration of potentially hazardous constituents in used oil samples taken from collectors and processors are statistically summarized according to the stage of processing. The concentration of hazardous constituents in generated processing residues are also summarized in this section.

4.2 PARTICIPANTS IN THE USED OIL MANAGEMENT SYSTEM

Although the processing technologies utilized by the used oil management system are relatively simplistic, the system itself is quite complex. There are literally hundreds of different types of companies involved in management practices as well as hundreds of pathways which generated used oil may follow on its way to reuse or disposal. Figure 2 (presented in Section 1) showed used oil flows through nine selected representative facility types involved in the collection and processing of used oils. All recovered oil is assumed to pass thrugh one or more of these model facility types. The flow to end-use markets was developed based upon a survey of companies representing each specific company type (5). Model facilities were selected to represent the most significant variations which exist in the types of companies which comprise the used oil management system.

The nine selected model facilities utilized to describe the used oil management system are listed and briefly defined according to size and operational characteristics in Table 30. Although nine models have been developed, there are only four basic types of companies involved in used oil management:*

(1) Independent collectors

(2) Minor processors

(3) Major processors

(4) Re-refiners

These basic company types are generally defined in Section 2 - Definitions. Later in this section, each company type is described in more detail according to processing technology, operations, product oil sales, and residue generation and management. These discussions are descriptive summaries based upon a more comprehensive characterization of the model facilities submitted separately to the U.S. EPA Office of Solid Waste (2). In that document, each of the nine selected models was characterized according to the following categories:

1. Size of company
2. Sources of oil
3. Capital equipment
4. Facility operations
5. Markets for collected/processed oil

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* A fifth company type is virgin fuel oil blenders who purchase used oil from collectors and processors and mix the oil with virgin fuels for sale to all sectors of society. These facilities are briefly discussed in Section 5 - Used Oil Marketing and Disposal.

Table 30

SELECTED MODEL FACILITIES IN THE USED OIL MANAGEMENT SYSTEM[*]

Facility type	Model abbreviation	Size of company	Operational characteristics
Independent Collector	IC	Small	Collects used oil; no processing; delivers primarily to processors but also end-users
Minor Processor	MP-1	Small	Collects used oil; settles water and/or sludge; sells primarily to end-users and fuel oil dealers, but also processors
Minor Processor	MP-2	Medium	Collects used oil; settles water and/or sludge using heat treatment; may handle other hazardous wastes; sells product oil to end-users and fuel oil dealers
Major Processor	MJP-1	Medium	Collects and purchases used oil; processes using heat treatment, emulsion breaking, and centrifugation; sells product oil to end-users and fuel oil dealers
Major Processor	MJP-2	Medium	Same as MJP-1, except other waste materials are handled in addition to used oil and product oil is sold only to fuel oil dealers
Major Processor	MJP-3	Medium	Same as MJP-1, except product oil may be blended with virgin fuel oils on-site
Major Processor	MJP-4	Large	Same as MJP-1, except other hazardous materials (e.g., solvents) are also handled which may be mixed with product oil
Re-Refiner	RR-1	Medium	Acid-clay re-refining technology
Re-Refiner	RR-2	Large	Vacuum distillation re-refining technology

[*] These nine facility types were selected to model the entire spectrum of facilities which exist in the used oil management system. Each model facility is described in detail in another EPA document (2).

[†] Small facilities process <1 million gal/yr; medium facilities process 1 to 5 million gal/yr; and large facilities process >5 million gal/year.

Source: Franklin Associates, Ltd. from a limited survey of the used oil management system (1982-83).

6. Other wastes handled
7. Residue generation and management
8. Administrative responsibilities
9. Other regulatory control options

In characterizing the models, ranges of reported conditions were developed and a best estimate of typical conditions was assumed. The selection of a best estimate was based upon information directly obtained by the research team from about one hundred industry representatives. No statistical procedures were used in the characterization process because of the nature of data gathering. The methodology consists of making responsible estimates using the random information obtained through site visits and telephone communications.

Figure 5 summarizes the flow of used oil from generators into the four basic types of companies in the management system. Independent collectors collect only about 25 percent of the oil which passes from generators into the management system. The majority (75 percent) is collected directly by the companies involved in processing or re-refining the oil. Independent collectors sell about 62 percent of their oil to processing companies, therefore 90 percent of the oil which enters the management system is ultimately processed to some degree. About two-thirds of the processed oil is handled by a major processing facility; 20 percent by a minor processing facility; and only 14 percent by a re-refiner.

4.2.1 Independent Collectors

There are several hundred independent companies in the United States which collect used oil (about 167 million gallons in 1983) and sell it to end-

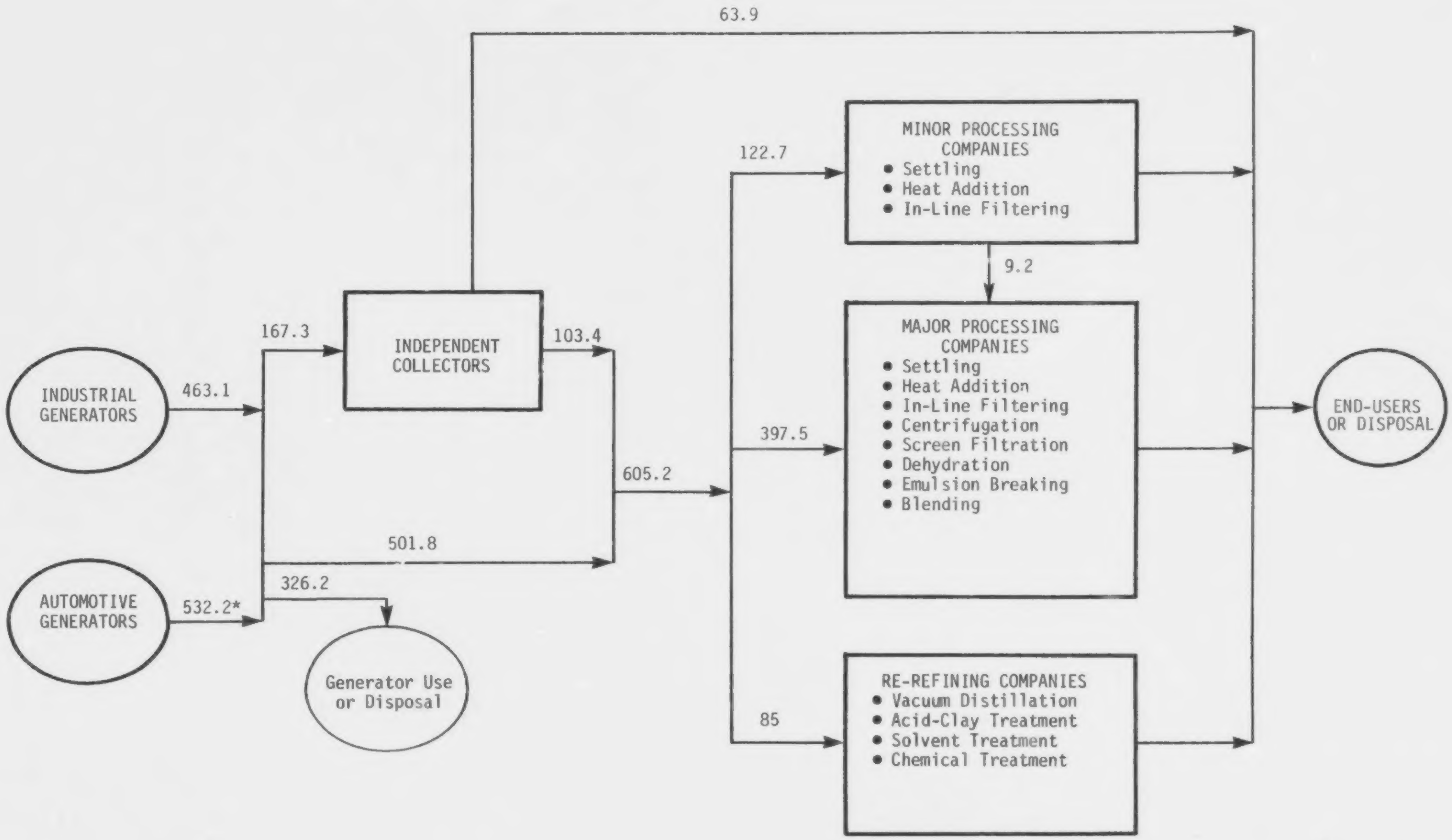
63.9
MINOR PROCESSING COMPANIES
• Settling
• Heat Addition
• In-Line Filtering
122.7
9.2
167.3
INDEPENDENT COLLECTORS
103.4
INDUSTRIAL GENERATORS
463.1
MAJOR PROCESSING COMPANIES
• Settling
• Heat Addition
• In-Line Filtering
• Centrifugation
• Screen Filtration
• Dehydration
• Emulsion Breaking
• Blending
397.5
605.2
END-USERS OR DISPOSAL
501.8
AUTOMOTIVE GENERATORS
532.2*
326.2
Generator Use or Disposal
RE-REFINING COMPANIES
• Vacuum Distillation
• Acid-Clay Treatment
• Solvent Treatment
• Chemical Treatment
85

Figure 5. Used oil flow into the management system.

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* Does not include automotive oil which is not recovered from DIYers.

Source: See Appendix C for the methodology for the development of the used oil flow.

use markets and/or to processors and re-refiners. These companies may store oil, but they do not process the oil to improve quality.

Although an independent collector may haul as much as one million gallons of used oil per year, a more typical volume would be about one-half of that amount. Most companies operate two collection vehicles and use 2 to 5 storage tanks (usually above-ground).

Independent collectors prefer to sell oil directly to users for fuel or as a dust suppressant because of price variations for markets. Prices received for these user markets are 30 to 80 percent higher than those received if the oil were sold as an intermediate product to a processor or re-refiner.

Independent collectors sell 35 percent of their oil directly to end-users (15 percent road oil/20 percent fuel). The remaining 65 percent is delivered to processors (45 percent) and re-refiners (20 percent).

4.2.2 Minor Processors

4.2.2.1 Processing Technology and Operation

The processing technology used by minor processors is quite simplistic by definition, including only in-line filtering and gravity settling with or without heat addition. Therefore, the only processing equipment that would be used to carry out these simple steps includes storage tanks, pumps, flexible hoses, rigid above or below ground metal pipe, and heating devices. Heating by minor processors is only to decrease viscosity and improve gravity settling. If heating is part of the minor processors' operations, used oil is sometimes burned to provide the needed energy.

There are 100 to 150 minor processors of used oil in the United States. Facility size varies from 250,000 to 5,000,000 gallons annual throughput.

Most minor processors collect all of their oil with their own collection vehicles; however, some companies report receiving up to 15 percent of their supply from independent collectors.

Minor processors operate and use variable numbers of collection vehicles and storage tanks depending on the volume of used oil handled. Typically, 3 to 6 collection vehicles are in operation and 5 to 10 storage tanks are used. Tanks are usually located directly on the ground surface. Some type of containment around a storage area is common. Minor processors may also use drums, surface impoundments, and collection basins to store oil or processing residues.

Many minor processors collect and handle other waste materials such as solvents. Some solvent mixing (usually high energy-nonchlorinated solvents) with used oil is not uncommon.

4.2.2.2 Product Oil Distribution

Minor processors market product oil in five different ways or they may burn it on-site for heat-induced gravity settling, for space heating, or for some other fuel consuming process operated on the facility site. The five general markets for product oil include (1) direct fuel sales, (2) virgin fuel oil dealers (V.F.O.D.), (3) non-fuel industrial uses (e.g., phosphate industry flotation oil), (4) road oiling, and (5) major waste oil processors. Of course, any given minor processor may market oil to a combination of these markets.

The markets and prices received for minor processor's product oil vary by region and season. Generally, a higher price is received for fuel markets (50-60¢/gal) than for other markets (35 to 50¢/gal).

The overall product distribution from the two types of minor processors (MP-1 and MP-2) is shown in Table 31.

TABLE 31. PRODUCT OIL DISTRIBUTION FROM MINOR PROCESSORS

Market	Waste Oil Distribution	
	(million gal)	(percent)
Direct Fuel Sales	33.0	28
Fuel Oil Dealers	56.4	49
Non-Fuel Industrial	6.1	5
Road Oiling	7.5	6
Major Processors/Re-refiners	9.2	8
On-Site Buring	4.4	4
Total	116.6*	100

* Does not include five percent losses in residue disposal.

Source: (5). See Appendix C.

4.2.2.3 Residue Generation and Management

The objectives of a minor processor is to improve oil quality to some degree making it an acceptable product for various markets. Quality improvement usually means the separation of unwanted materials from the oil, thus creating waste products Minor processing generates four residues including filter residue, wastewater, sludge, and tank bottoms. Sludge differs from tank bottoms in that sludge is generated rapidly as part of the normal layering associated with settling. Tank bottoms are the thick tar-like layer which forms slowly over a period of months or years. Some processors may not separate out the sludge layer, but instead simply pass it along with their product oil. In addition, some processors may never clean their tanks and thus never generate tank bottoms. But typically, most minor processors generate variable amounts of all four waste products.

Figure 6 summarizes residue generation and management for minor processors. Typical generation rates for each residue type are shown below.

- In-Line Filtered Residue - 100 to 700 pounds per year
- Settled Wastewater - 25,000 to 500,000 gallons per year
- Oily Sludge - None* to 100,000 gallons per year
- Tank Bottoms - None* to 10,000 gallons per year

4.2.3 Major Processors

4.2.3.1 Processing Technology and Operation

By definition, a major processor is more sophisticated than a minor processor with respect to processing technology. In addition to the processing equipment used to carry out the minor processor's simple treatment steps (storage tanks, pumps, flexible hoses, rigid above- or below-ground metal pipe, and heating devices), a major processor uses other

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* The non-existence of oily sludge and tank bottoms is based upon operational characteristics of facilities which do not separate this material regardless of whether it is present or not (e.g., it is marketed with the product).

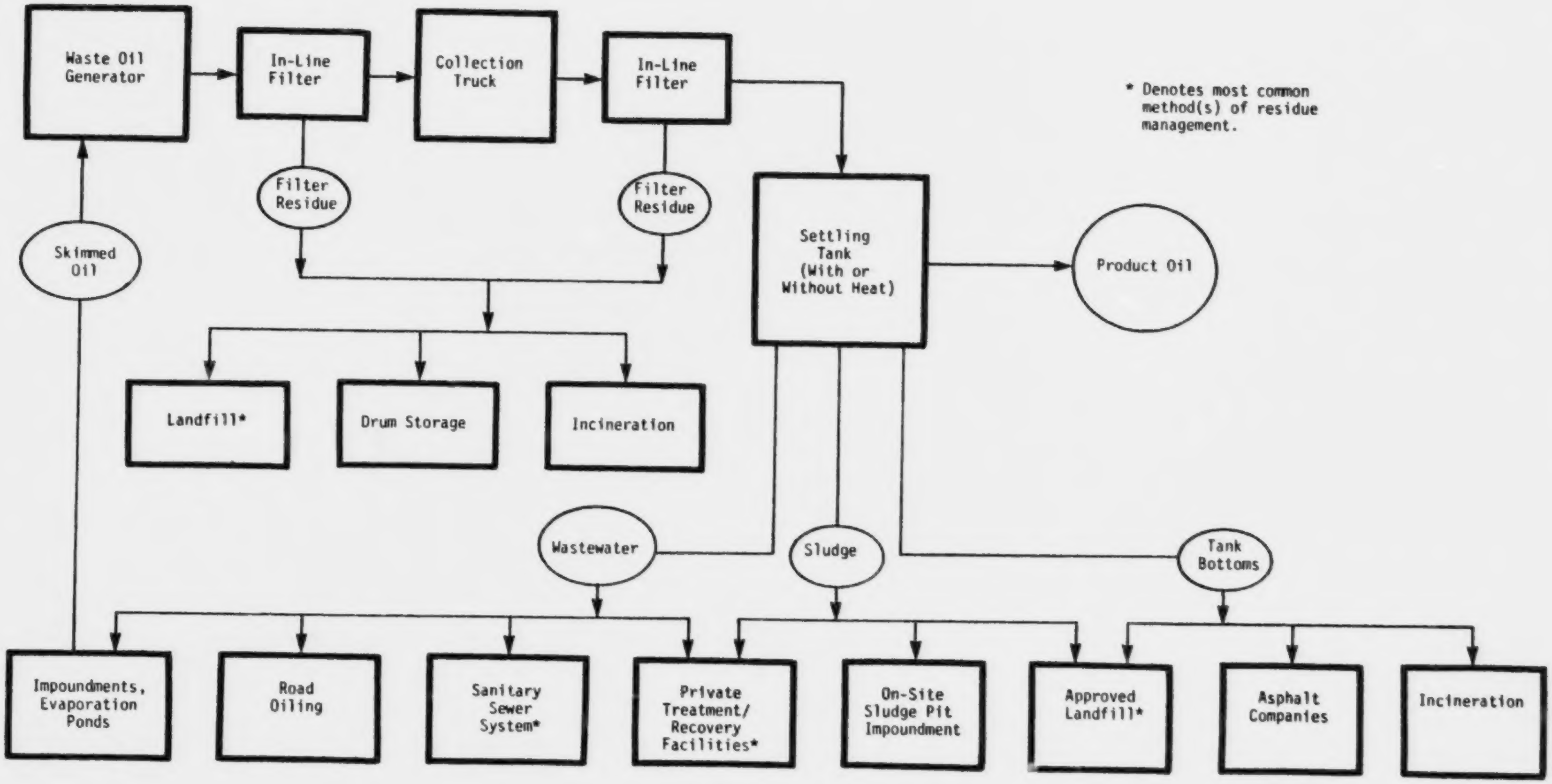
Waste Oil Generator
In-Line Filter
Collection Truck
In-Line Filter
Filter Residue
Filter Residue
Skimmed Oil
Settling Tank (With or Without Heat)
Product Oil
* Denotes most common method(s) of residue management.
Landfill*
Drum Storage
Incineration
Wastewater
Sludge
Tank Bottoms
Impoundments, Evaporation Ponds
Road Oiling
Sanitary Sewer System*
Private Treatment/ Recovery Facilities*
On-Site Sludge Pit Impoundment
Approved Landfill*
Asphalt Companies
Incineration

Figure 6. Minor processor residue generation and management.

Note: * Denotes most common methods of residue management.

tertiary treatment devices to further increase oil quality or to blend or mix materials into the oil. Additional equipment which is used includes distillation towers, large filter screens, centrifuges, agitators, and blending devices. Distillation towers are used to evaporate light fuel fractions and water from the waste oil. The hydrocarbons are collected while the evaporated water vapor is released to the atmosphere. None of the lube fraction is distilled. Filter screens and centrifuges separate fine solids from the oil. Agitators are used to mix emulsion-breaking chemicals in waste oil. Blending devices are used to mix virgin fuel oil or other material into product oil.

The number of major processor companies is similar to that of minor processor companies (100 to 150). Generally, major processors are larger than minor processors, but company size is quite variable ranging from about 1,000,000 to 10,000,000 gallons of oil per year. Those facilities involved in blending used oil with virgin fuel oils tend to be larger than those which do not blend.

Although major processors all operate collection fleets (4 to 20 vehicles), many purchase additional oil from independent collectors. Overall, 20 percent of the oil processed in major processing facilities is received from independent collectors.

Most moderate and large sized major processors own and operate large transport vehicles (6,000 to 9,000 gallons) in addition to smaller route trucks (1,500 to 4,000 gallons). Transports are used to bring collected oil to the processing facility from satellite storage locations and independent collector storage, and to deliver product oil to end-use markets.

Major processor storage is quite variable with respect to total capacity and number of tanks. Some companies have only a few large tanks. Others have as many as 30 to 40 tanks of smaller miscellaneous sizes. Most typical facilities have several tanks of moderate size to give a total storage capacity of about 200,000 gallons. Most tanks are built directly on the ground surface. Spill containment around storage areas is common for most facilities. Impoundments, drums, and collection basins can be found on many major processor sites as alternatives for oil and residue storage and disposal.

A significant number of major processing companies are licensed to transport and process hazardous wastes, particularly solvents. In some cases, solvents (usually non-chlorinated), are mixed with oil as a means of disposal and to decrease used oil viscosity.

4.2.3.2 Product Oil Distribution

Major processors market product waste oil in four different ways or they may burn it on-site for heat-induced gravity settling, for space heating, or for some other fuel-consuming process operated on the facility site, such as distillation. The four general markets for product oil include (1) direct fuel sales, (2) virgin fuel oil dealers (V.F.O.D.), (3) non-fuel industrial uses (e.g., phosphate industry flotation oil), and (4) road oiling. Any given major processor may market oil to a combination of these markets.

The markets and prices received for major processors' product oil vary tremendously by region and season. The highest price received is for direct fuel sales, primarily to asphalt plants or large industrial boilers (50 to 65¢/gal). Fuel oil dealers pay 40 to 60¢/gal and the non-fuel uses including road oiling pay 40 to 55¢/gal. Generally, major processors receive two to three cents more per gallon for most end-uses than minor processors.

Table 26 shows the overall product oil distribution from the four types of major processors defined in Table 32. Major processors who blend or mix used oil with virgin oil or other waste materials are more likely to sell their product directly to users than to virgin fuel oil dealers.

TABLE 32. PRODUCT OIL DISTRIBUTION FROM MAJOR PROCESSORS

Market	Waste Oil Distribution (million gal)*	(percent)
Direct Fuel Sales	205.7	53
Fuel Oil Dealers	132.4	35
Non-Fuel Industrial	19.8	5
Road Oiling	8.2	2
On-Site Burning	20.3	5
Total	386.4*	100

*Does not include five percent losses in residue disposal.

Source: (5), see Appendix C.

4.2.3.3 Residue Generation and Management

Major processing technologies are designed to remove constituents from used oil. The treatment methods typically yield five residues including filter residies, wastewater, centrifuge solids, oily sludge, and tank bottoms. Every major processor does not generate all of the five residues because specific operating practices which influence residue generation differ. For example, a company may never clean out storage tanks and, therefore, effectively not generate tank bottoms.

Figure 7 summarizes residue generation and management for major processors. Typical generation rates for each residue type are shown below.

- In-Line Filter Residue - 200 to 1,000 pounds per year
- Settled Wastewater - 50,000 to 1,000,000 gallons per year
- Oily Sludge - None* to 100,000 gallons per year
- Tank Bottoms - None* to 25,000 gallons per year
- Centrifuge or Filter Screen Solids - None to 50,000 pounds per year

4.2.4 Re-refiners

4.2.4.1 Processing Technology and Operation

Unlike the relatively consistent and simple reprocessor technologies, re-refining operations differ considerably and are much more complex. Although the technical differences in processing alternatives are important, details regarding those differences require substantial explanation and are not included in this report.† Rather, the major distinct types of re-refining technologies are listed:

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* The non-existence of oily sludge and tank bottoms is based upon operational characteristics of facilities which do not separate this material regardless of whether it is present or not (e.g., it is marketed with the product).

† See References (11,15,16, and 34) for descriptions of re-refining technologies.

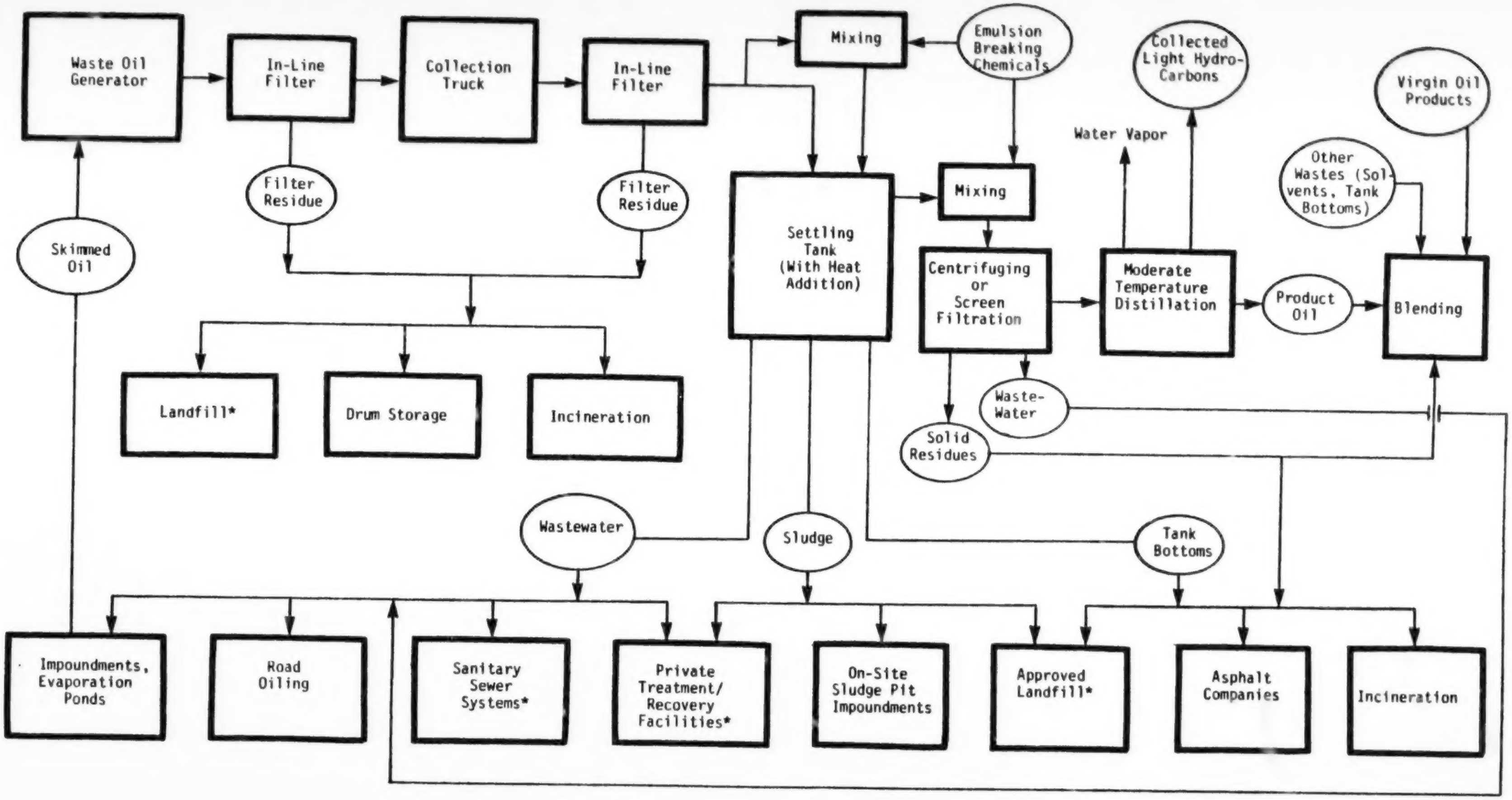
Waste Oil Generator
In-Line Filter
Collection Truck
In-Line Filter
Mixing
Emulsion Breaking Chemicals
Collected Light Hydro-Carbons
Virgin Oil Products
Filter Residue
Filter Residue
Skimmed Oil
Settling Tank (With Heat Addition)
Mixing
Water Vapor
Other Wastes (Sol-vents, Tank Bottoms)
Centrifuging or Screen Filtration
Moderate Temperature Distillation
Product Oil
Blending
Landfill*
Drum Storage
Incineration
Waste-Water
Solid Residues
Wastewater
Sludge
Tank Bottoms
Impoundments, Evaporation Ponds
Road Oiling
Sanitary Sewer Systems*
Private Treatment/ Recovery Facilities*
On-Site Sludge Pit Impoundments
Approved Landfill*
Asphalt Companies
Incineration

Figure 7. Major processor residue generation and management.

Note: * Denotes most common methods of residue management.

(1) Solvent treatment/distillation/hydrotreating

(2) Acid/clay

(3) Vacuum distillation/clay polishing

(4) Chemical treatment/demetallization/clay polishing

The above distinctions are very important for several reasons including waste materials generated, coproduct and byproduct marketability, and the applicability of environmental regulation and control options.

Much of the equipment used by processors such as storage tanks, pumps, flexible hoses, rigid above and below ground metal pipe, heating devices, dehydration units, and condensers are also used by re-refiners. However, additional tertiary processing equipment is also utilized by re-refiners such as acid treatment vessels, vacuum distillation towers, and clay contacting vessels.

Some re-refiners are also involved in used oil reprocessing, either on a regular basis or according to product demand and feedstock quality. The equipment required to reprocess used oil is contained as part of the refining equipment. The reprocessing option merely bypasses some re-refining processing steps.

There are only 12 to 16 operating re-refiners in 1983; however, there are some indications that this number will increase during the next decade.

Due to economies of scale, re-refiners tend to be larger than used oil processors. Modern re-refiners, which use primarily vacuum distillation technologies, process up to 20 million gallons of used oil per year. Typical facilities process about 8 to 10 million gallons. The older and less common acid/clay facilities are smaller (about 2 to 4 million gallons per year). Only 2 or 3 acid/clay facilities were in operation in 1983.

All re-refiners operate collection fleets which typically secure two-thirds of the oil to be re-refined. The remaining one-third is obtained from independent collectors.

In addition to the 5 to 15 collection vehicles operated by re-refiners, most companies own large transport vehicles to bring feedstock to their facilities from distant points of collection and to deliver finished products.

Re-refiners use many small to medium-sized storage tanks rather than fewer large tanks. This is because re-refiners are likely to segregate feedstocks and finished products according to quality and end-use. (Processors are more likely to mix oil and therefore need fewer tanks to accommodate desirable segregation.) Typical re-refiners have 20 to 30 storage tanks, most of which are above-ground tanks built directly on the ground surface. Spill containment around storage areas is common.

4.2.4.2 Product Oil Distribution

The markets for re-refined products are better defined and understood than those for reprocessors' product oil. All facilities produce a re-refined lube basestock and a distilled light fuel fraction, most of which is burned on-site to provide heating requirements. Other coproducts with marginal value are also produced including distillation bottoms for use as an asphalt extender and demetallizing filter cake for use in highway construction.

The lube oil yield and quality differ for various technologies. For example, vacuum distillation processes yield about 10 percent more lube than acid/clay processes (75 compared to 65 percent of input). In addition, the basestocks produced in the vacuum distillation processes are more valuable than those produced by acid/clay processes because of quality differences. The acid/clay technologies are less capable than distillation processes of completely cleansing use oil of some metals from additive packages such as barium and zinc (34).

The overall distribution of used oil which is delivered to re-refiners is summarized in Table 33.

TABLE 33. DISTRIBUTION OF USED OIL FROM RE-REFINERS

End-Use	Oil Distribution (million gal)	(percent)
Re-refined Lube Oil	62.7	74
Distillate Fuel	6.0	7
Distillation Bottoms	9.0	11
Disposal*	7.3	8
Total	85	100

* Includes oil contained in process residues including spent clay, acid sludge, wastewater, etc.

Source: (5), see Appendix C.

4.2.4.3 Residue Generation and Disposal

In recent years two major reports have been published which evaluated residue generation and disposal at re-refining facilities (16,19). These documents comprehensively assess the characteristics and quantities of residues as well as current and potential methods for their management. Figures 8 and 9 illustrate the sources of residues for the two major re-refining technologies currently in operation (acid/clay and vacuum distillation, respectively) and reasonable management alternatives. Typical generation rates for the reported residues are listed on the second following page.

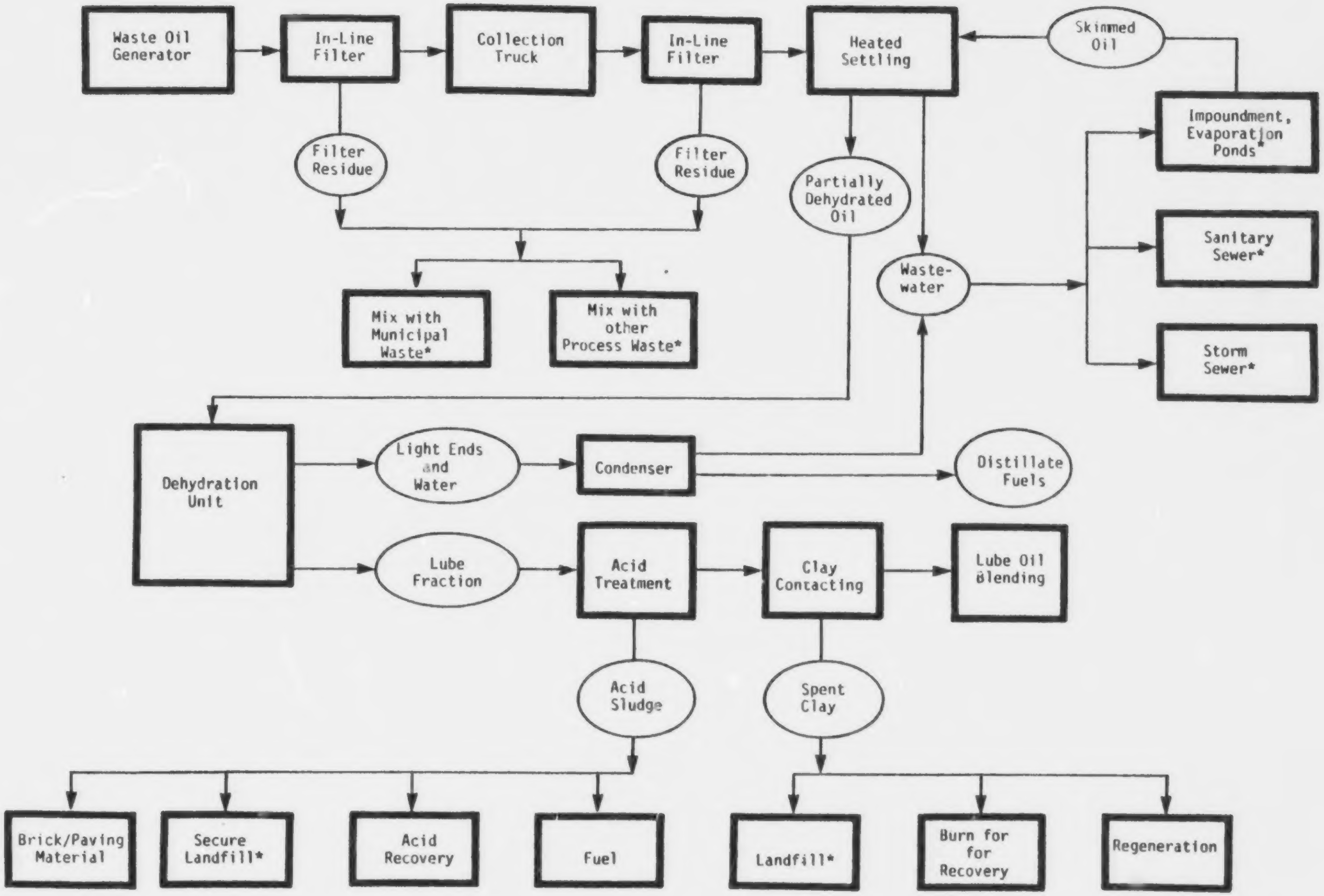
Waste Oil Generator
In-Line Filter
Collection Truck
In-Line Filter
Heated Settling
Skimmed Oil
Impoundment, Evaporation Ponds*
Sanitary Sewer*
Storm Sewer*
Filter Residue
Filter Residue
Partially Dehydrated Oil
Waste-water
Mix with Municipal Waste*
Mix with other Process Waste*
Dehydration Unit
Light Ends and Water
Condenser
Distillate Fuels
Lube Fraction
Acid Treatment
Clay Contacting
Lube Oil Blending
Acid Sludge
Spent Clay
Brick/Paving Material
Secure Landfill*
Acid Recovery
Fuel
Landfill*
Burn for for Recovery
Regeneration

Figure 8. Acid/clay re-refiner residue generation and management.

Note: * Denotes most common methods of residue management.

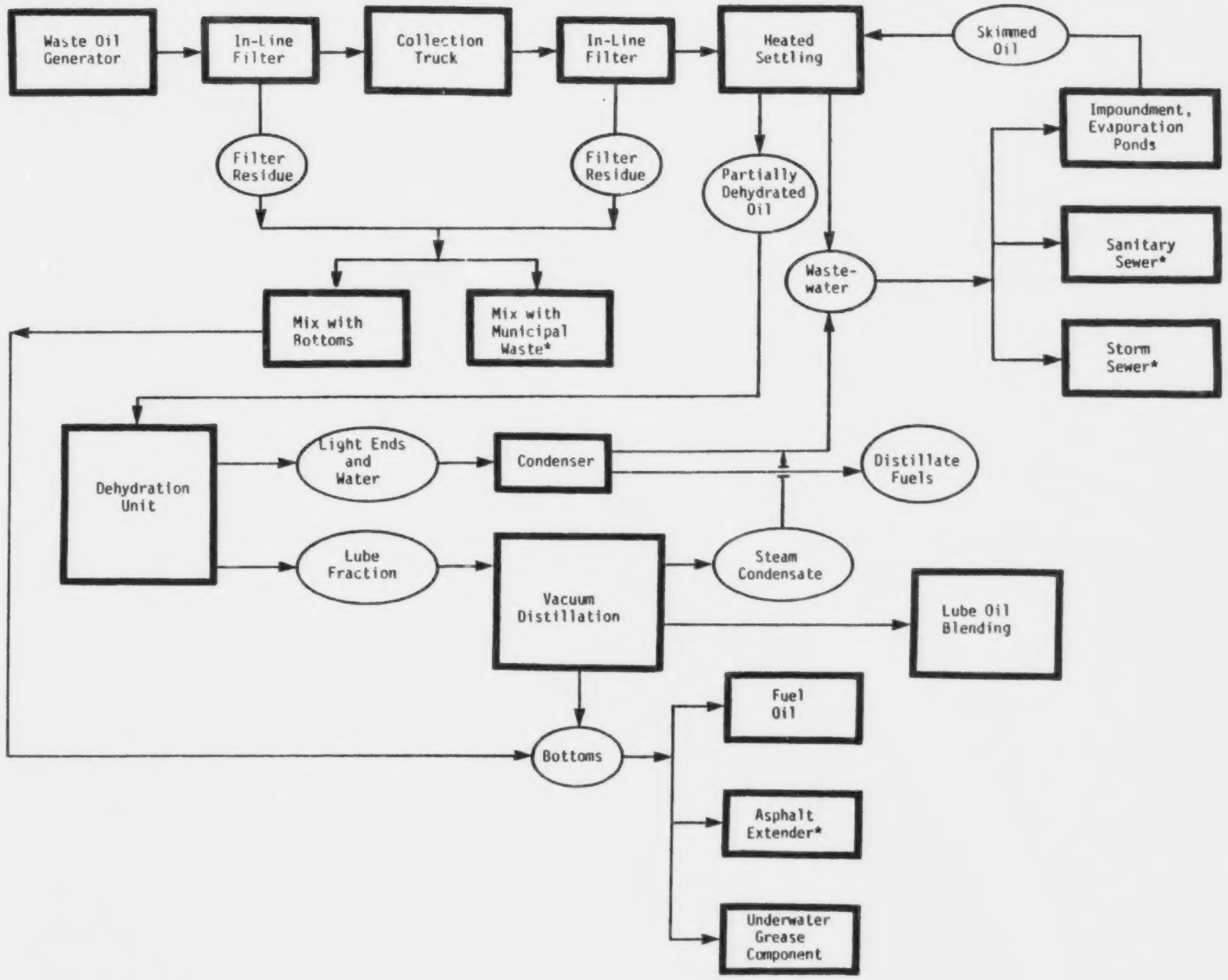
Waste Oil Generator
In-Line Filter
Collection Truck
In-Line Filter
Heated Settling
Skimmed Oil
Filter Residue
Filter Residue
Partially Dehydrated Oil
Impoundment, Evaporation Ponds
Sanitary Sewer*
Storm Sewer*
Waste-water
Mix with Bottoms
Mix with Municipal Waste*
Dehydration Unit
Light Ends and Water
Condenser
Distillate Fuels
Lube Fraction
Vacuum Distillation
Steam Condensate
Lube Oil Blending
Bottoms
Fuel Oil
Asphalt Extender*
Underwater Grease Component

Figure 9. Vacuum distillation re-refiner residue generation and management.

Note: * Denotes most common methods of residue management.

Acid Clay Re-refiner

- In-Line Filtered Residue - 200 to 2,000 pounds per year
- Wastewater - 100,000 to 1,000,000 gallons per year
- Acid Sludge - 250,000 to 750,000 gallons per year
- Spent Clay - 300 to 500 tons per year

Vacuum Distillation Re-refiner

- In-Line Filtered Residue - 500 to 5,000 pounds per year
- Wastewater - 250,000 to 2,000,000 gallons per year
- Spent Clay - 500 to 2,000 tons per year

4.2.5 Summary of Collector and Processor Companies

Three tables were developed to summarize the major characteristics of collector and processor companies. Table 34 characterizes the nine typical company types with respect to size, oil source, equipment, and operations. Table 35 summarizes residue generation and management and Table 36 summarizes end-use markets.

It is important to emphasize that the typical company characteristics in Table 34 were developed from a wide range of actual industry characteristics. The information in Table 34 is typical rather than average. The methodology did not use statistical procedures. Responsible estimates were made based upon data and information obtained through telephone interviews and site visits (5).

Table 34

CHARACTERIZATION OF NINE TYPICAL COMPANY TYPES INVOLVED IN USED OIL MANAGEMENT[*]

Characteristic[†]	Independent Collectors	Minor Processors		Major Processors				Re-Refiners	
		MP-1	MP-2	MJP-1	MJP-2	MJP-3	MJP-4	Vacuum Distillation	Acid-Clay
Size of Company									
Number of employees	2	4	7	8	8	8	30	30	20
Annual oil volume (10^6 gal)	0.5	0.75	1.5	2.5	2.5	2.5	7.5	8.0	3.5
Source of Oil									
Automotive (%)	100	75	75	65	65	65	65	65	65
Industrial (%)	0	25	25	35	35	35	35	35	35
Collected from Generators (%)	100	100	100	80	80	80	80	67	67
Purchased from Independent Collectors (%)	0	0	0	20	20	20	20	33	33
1983 Price Paid (c/gal)									
To Generator	20	20	20	20	20	20	20	20	20
To Independent Collector	NA	NA	NA	35	35	35	35	35	35
Equipment									
Number of Vehicles									
Collection	2	3	5	5	5	5	15	10	7
Transport	0	0	1	1	1	1	5	5	3
Storage									
Number of Tanks	4	5	10	12	12	12	25	25	17
Total Tank Capacity (10^3 gal)	37	74	158	205	205	205	508	725	300
Other Storage Devices[‡]	None	None	None	None	S.I.	None	S.I.	None	S.I.
Operations[§]									
Generator Accounts per Day per Vehicle	15	10	10	10	10	10	10	10	10
Sampling/Analysis Programs	c	c	b	b	b	b	a	a	a
Spill Containment	b	b	a	a	a	a	a	a	a
Liner Usage	c	c	c	c	b	c	b	b	b
Groundwater Monitoring	c	c	c	c	c	c	c	c	c

[*] A wide range of company characteristics were identified for each basic company type (see discussion in text). See Table 30 for definitions of company types.

[†] Residue generation and markets are summarized in Tables 35 and 36.

[‡] (S.I.) indicates surface impoundments are typically used.

[§] Operational usage codes: (a) commonly practiced, (b) moderately practiced, (c) rarely practiced.

Source: Franklin Associates, Ltd.

Table 35

SUMMARY OF RESIDUE GENERATION AND MANAGEMENT BY TYPICAL USED OIL MANAGEMENT COMPANIES*
(annual quantities per facility)

Residue	Independent collectors		Minor processors		Major processors		Re-Refiners			
							Vacuum distillation		Acid-Clay	
	Low	High	Low	High	Low	High	Low	High	Low	High
In-line filter residue - lb	100	500	200	700	200	1,000	500	5,000	200	2,000
Settled wastewater - 1,000 gal	N†	N	25	500	50	1,000	250	2,000	100	1,000
Oily sludge - 1,000 gal	N	N	N	100	N	100	N	N	N	N
Tank bottoms - 1,000 gal	N	N	N	10	N	25	N	30	N	15
Centrifuge or filter screen solids - 1,000 lb	N	N	N	N	N	50	N	N	N	N
Spent clay - tons	N	N	N	N	N	N	500	2,000	300	500
Acid sludge - 1,000 gal	N	N	N	N	N	N	N	N	250	750

* The wide ranges for estimates of residue quantities occur because of diverse processing technologies, variable used oil quality, and a general lack of data on generation rates.

† An (N) indicates not generated, or not separated.

Source: Franklin Associates, Ltd., from a limited survey of the used oil management industry.

Table 36

SUMMARY OF END-USE MARKETS FOR USED OIL MANAGEMENT COMPANIES*†

End-Use market	Independent Collectors	Minor Processors		Major Processors		Re-Refiners	
		MP-1	MP-2	MJP-1/MJP-2	MJP-3/MJP-4	Vacuum Distillation	Acid-Clay
Direct fuel sales	10	25	30	45	60	-	-
Fuel oil dealers	10	45	50	40	30	-	-
Non-fuel industrial‡	-	5	5	8	3	12	0
Road oiling	15	10	5	2	2	-	-
Major processors/ Re-refiners	65	15	5	-	-	-	-
On-site fuel	-	-	5	5	5	7§	7§
Lube oil	-	-	-	-	-	75	65
Total	100	100	100	100	100	94**	82**

* See Table 30 for definitions of company types.

† End-use market distributions are shown as percent of total for each market type.

‡ Includes asphalt extenders, flotation oils, form oils, etc.

§ It was assumed that the distillate fuel fraction is burned on-site for process fuel.

** Totals do not equal 100 due to oil losses in processing. Collector and processor losses are not accounted for in this summary.

Source: Franklin Associates, Ltd. from a survey of the used oil management system.

The data in Table 35 show that wide ranges in residue generation exist at used oil processing facilities. This is due to significant variations in processing technologies, used oil quality, and company management practices. In some cases residues are generated but not acknowledged by company management; therefore, it is effectively not generated. For example, settled wastewater, sludge, and even tank bottoms are generated at any facility which stores used oil. However, many facilities do not separate these materials from the oil. They may pass wastewater and settled sludge along with product oil to an end-user or other processor, or they may leave tank bottoms in their tanks for years because it accumulates very slowly (e.g., tank bottoms).

Table 36 compares the percent distribution of product oil from the selected model facilities. These percents are the estimated average distribution for all facilities of these types rather than the typical data presented in most of the model facility characterization tables. Except for the independent collectors who sell most of their oil to processors and re-refiners, most of the product oil from all facility types enters the fuel market. Similar used oil quantities are sold directly to burners and to virgin fuel oil dealers. Also, similar amounts of oil are believed to be burned directly and in blended form with virgin fuels. Road oiling is a major market for only two facility types: independent collectors and one minor processor (MP-1). All facility types which require process heat use used oil to provide some of their total energy requirements.

4.3 EFFECTS OF PROCESSING ON USED OIL COMPOSITION

Section 1.4 presented an overview of used oil contamination by potentially hazardous constituents, and Section 3.4 presented contamination according to oil source. Those data are also relevant to the composition of the oil which is stored and processed on-site at used oil management system companies.

In this section, some data are presented on the effects of processing on the presence of the hazardous constituents in used oil. Overall, data are lacking and clear conclusions regarding the efficiencies of contaminant removal through various processing steps cannot be made. Therefore, the quantitative part of this presentation is limited to an assessment of the effects of settling on contaminant removal and a comparison of incoming waste oil quality with product oil quality. A qualitative discussion of the effects of some processing steps is also included.

Table 37 provides some data on the effects of settling on metals and total chlorine concentrations in top and bottom layers of stored used oil. The data are limited and inconclusive; however, the metals do appear to be somewhat higher in the bottom layers of stored oil. Relatively more data are available for total chlorine concentration which seems to be unaffected by settling.

The presence of various constituents in layers of stored used oil depend on several factors including the water content of the oil, the solubility of the constituents in water and oil, and the chemical and physical form of the constituents (e.g., particulate form). The measured effects of settling on constituent concentrations also depend on sampling techniques.

Table 37

EFFECTS OF SETTLING ON METALS AND TOTAL CHLORINE CONCENTRATIONS IN STORED USED OIL*

	Storage Locations‡										
	1	2	3	4	5	6	7	8	9	10	Average (%)
Metals											
Arsenic	0	0	-	0	0	0	-	-	-	-	0
Barium	9.1	11.8	-	-	-25.0	1,361.5	-	-	-	-	339.4
Cadmium	-†	-	-	-	-	-	-	-	-	-	-
Chromium	4.2	25.4	-	-	-15.4	-76.9	-	-	-	-	-15.7
Lead	0	40.1	-	-	-9.1	595.6	-	-	-	-	156.9
Zinc	4.5	12.8	-	-	-15.4	325.0	-	-	-	-	81.7
Total Chlorine	0	-74.6	366.7	-6.5	-40.0	27.0	-58.8	220	171.4	-80.3	52.5

* Values shown equal percent difference, determined by: $\frac{\text{bottom layer concentration - top layer concentration}}{\text{top layer concentration}} \times 100\%$.

For example: Sample 1, barium, shows 9.1%. This means the barium concentration in the bottom layer is 9.1% higher than in the top layer.

† Means either one or both samples did not detect **constituent**, or the concentration of the constituent was not measured.

‡ Numbers 1 to 5 represent used oil storage in tanks; numbers 6-10 represent used oil stored in surface impoundments.

Source: Appendix A data.

For example, when samples were taken from bottom layers, how close to the bottom were the samples taken? Were any tank bottoms taken? Was an oily water sample taken? Was it a settled oily sludge with a high BS&W content? Or, was it mostly straight mineral oil? For the data in Table 37, answers to these questions are unknown; thus the data are of limited value.

Many of the 1,071 used oil samples were identified as either incoming unprocessed waste oil or processed product oil. The data do not permit the determination of the effectiveness of contaminant removal for specific processes because a given batch of used oil was never sampled as it moved through the processing scheme. However, since nearly 400 used oil samples can be identified as processed or unprocessed,* a comparison of these two groups does provide some indication of the overall effectiveness of processing in general. Tables 38 and 39 show the concentrations of potentially hazardous constituents in unprocessed and processed used oil, respectively. Table 40 compares the mean, median, and 90th percentile concentrations for several constituents in unprocessed and processed used oil. It also shows the percent difference in median concentrations.

The results of the unprocessed/processed comparison in Table 40 are unexpected. The median concentration of virtually all of the hazardous constituents is higher in the product oil than in the unprocessed used oil. Quite surprising was the fact that lead concentration in product oil was about 87 percent higher than in unprocessed oil. Other metals ranged from 3 to 70 percent higher in product oil. The higher measured values for all

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* In the processed/unprocessed classification no attempt was made to distinguish between specific processing technologies.

Table 38

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN UNPROCESSED USED OIL

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	291	74	25	16.8	5	5	17	2	94
Barium	291	272	93	111.6	39	110	210	<0.5	1,170
Cadmium	291	70	24	4.0	7	8	10	<0.5	57
Lead	291	258	88	598.5	259	745	1,200	<0.5	15,000
Chromium	256	192	75	45.0	5.8	19	87	<0.5	571
Zinc	288	284	98	538.2	330	741	1,100	2.3	8,610
Chlorinated Solvents									
Dichlorodifluoromethane					NOT MEASURED				
Trichlorotrifluoroethane					NOT MEASURED				
1,1,1-Trichloroethane	265	140	52	3,298.4	100	1,400	4,500	<1	36,000
Trichloroethylene	265	71	26	2,032.2	100	100	500	<1	26,000
Tetrachloroethylene	264	130	49	2,362.1	100	540	2,100	<2	32,000
Total Chlorine	291	278	96	4,397	1,700	4,200	9,600	<100	86,700
Other Organics									
Benzene	105	46	43	1,493.2	15	100	300	<1	55,000
Toluene	106	83	78	2,199.1	230	800	2,900	<1	55,000
Xylenes	106	85	80	2,466.4	540	1,200	1,900	<2	57,000
Naphthalane					NOT MEASURED				
Benzo(a)anthracene					NOT MEASURED				
Benzo(a)pyrene					NOT MEASURED				
PCBs	266	39	14	79	5	10	32	0.53	1,900

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

Table 39

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN PRODUCT OIL FROM USED OIL PROCESSING FACILITIES

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	105	34	32	21.5	5	13	22	<5	58
Barium	105	96	91	153.3	50	160	312	1.9	1,710
Cadmium	105	7	6	4.5	8	10	10	0.5	10
Lead	105	95	90	547.8	484	771	942	5	3,250
Chromium	71	44	61	23.4	6	12	27	0.5	324
Zinc	106	104	98	578.7	540	730	1,090	5	2,050
Chlorinated Solvents									
Dichlorodifluoromethane				NOT MEASURED					
Trichlorotrifluoroethane				NOT MEASURED					
1,1,1-Trichloroethane	101	65	64	2,681.0	400	2,000	4,400	<7	14,000
Trichloroethylene	101	51	50	2,464.1	200	500	1,500	<7	40,000
Tetrachloroethylene	101	59	58	1,660.6	200	1,000	2,600	<7	9,300
Total Chlorine	104	102	98	4,900	2,900	6,100	11,400	<100	25,800
Other Organics									
Benzene	9	4	44	325.5	16	30	110	<7	1,100
Toluene	10	9	89	1,459.4	270	600	1,600	<15	9,100
Xylenes	10	8	79	2,346.3	730	1,100	2,200	<7	12,000
Naphthalene				NOT MEASURED					
Benzo(a)anthracene				NOT MEASURED					
Benzo(a)pyrene				NOT MEASURED					
PCBs	100	10	9	16.5	10	12	50	1	100

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

Table 40

COMPARISON OF CONTAMINANT CONCENTRATIONS IN UNPROCESSED AND PROCESSED USED OIL

(ppm)

	Unprocessed Used Oil			Product Oil			Percent difference in median†
	mean*	median	90th percentile	mean*	median	90th percentile	
Metals							
Arsenic	16.8	5	17	21.5	5	22	0
Barium	111.6	39	210	153.3	50	312	+28.2
Cadmium	4.0	7	10	4.5	8	10	+14.3
Chromium	45.0	5.8	87	23.4	6	27	+3.4
Lead	598.5	259	1,200	547.8	484	942	+86.9
Zinc	538.2	330	1,100	578.7	540	1,090	+57.6
Total Chlorine	4,397	1,700	9,600	4,900	2,900	11,400	+70.6
Chlorinated Solvents							
1,1,1-Trichloroethane	3,298	100	4,500	2,681	400	4,400	+300.0
Trichloroethylene	2,032	100	500	2,464	200	1,500	+100.0
Tetrachloroethylene	2,362	100	2,100	1,661	200	2,600	+100.0
Aromatics							
Benzene	1,493	15	300	326	16	110	+6.7
Toluene	2,199	230	2,900	1,459	270	1,600	+17.4
Xylenes	2,466	540	1,900	2,346	730	2,200	+35.2
PCBs‡	79	5	32	16.5	10	50	+100.0

* Calculated for detected concentrations only.

† Calculated by: $\frac{\text{Product Oil Value} - \text{Unprocessed Oil Value}}{\text{Unprocessed Oil Value}} \times 100\%$. A negative sign indicates that the value was higher in unprocessed oil.

‡ All values calculated for detected concentrations only. Unprocessed oil had 14 percent detection while processed had 9 percent detection.

Source: Appendix A data.

chlorinated and aromatic solvents is somewhat surprising as well, since heat treatment should separate these volatile organics from the product oil. The significantly larger median concentrations for these volatile compounds are probably more, due to anomalies in the data, than to real differences. In some cases these light fractions are condensed by the processor; however, in other cases they are emitted to the atmosphere with steam which is also driven from the oil. Overall, one would expect processed oil (particularly from major processing facilities) to have lower levels of chlorinated and aromatic solvents than unprocessed oil.

In summary, used oil processing in 1983 is primarily to remove water, solids, and perhaps the light hydrocarbons which contaminate the oil. The data in Tables 38 to 40 show that many of the potentially hazardous constituents which are solubilized in the oil are barely affected by any processing short of re-refining.* Unless the constituents are present in particulate form or solubilized in a separable water fraction, the processing will usually not remove them.

4.4 CONTAMINATION OF USED OIL PROCESSING RESIDUES

Despite the low level effectiveness of many used oil processing technologies to remove the potentially hazardous constituents in the oil, the residues which are generated by collectors, processors, and re-refiners do contain variable levels of most of the constituents. The concentrations of these hazardous constituents in processing residues are summarized in this section. A separate discussion of the contamination of each of the major residues and a miscellaneous group of residues follows.

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* The effects of re-refining on oil quality are examined in Section 5 - Used Oil Marketing and Disposal.

4.4.1 Settled Sludges Generated During Used Oil Storage and Processing

Settled sludges can result from storage of used oil or as part of the processing to remove water and solids from the oil. Tank bottoms are not included in this category. The bottom sediment and water content (BS&W) of settled sludges ranges from 30 to over 90 percent. There is no criterion for BS&W which distinguishes a bottom layer of stored oil from a settled sludge. It is important to emphasize that some collectors and processors do not acknowledge the presence of this settled material; instead, they routinely pump their tanks dry. Other processors separate this material and pass it on to a more sophisticated processor for additional treatment and oil recovery.

Table 41 shows that the presence of potentially hazardous constituents in settled sludges is not very different from those levels measured in used oils. This is not surprising since the oil content in these sludges can be more than 50 percent. The composition data show that a settled sludge can contain several listed hazardous constituents. However, the contaminants do not appear to concentrate in the settled sludges.

4.4.2 Wastewater Separated from Used Oils

During processing a distinct free-water fraction is separated from used oils. This is in addition to the water which is tied up in oil-emulsions which comprise much of a settled sludge. Table 42 shows the levels of contaminants measured in wastewater samples. The differences in wastewater composition and used oil composition are dependent upon the solubility of

Table 41

SUMMARY OF CONTAMINANT LEVELS IN SETTLED SLUDGES GENERATED DURING WASTE OIL STORAGE AND PROCESSING

	Total analyzed samples	Samples with detected contaminant		Mean concentration* (ppm)	Median concentration (ppm)	Concentration at 75th percentile (ppm)	Concentration at 75th percentile (ppm)	Concentration range (ppm)	
		number	percent					Low	High
Metals									
Arsenic	41	10	24	11	<5	<5	12	0.013	24
Barium	47	43	91	416	70	310	1,200	0.21	3,610
Cadmium	40	11	28	63	<7	<10	48	0.02	216
Chromium	37	30	81	215	20	135	714	<0.5	2,130
Lead	50	42	84	802	300	993	1,400	0.02	7,770
Zinc	47	46	98	568	259	650	1,550	0.09	3,150
Chlorinated Solvents									
Dichlorodifluoromethane	8	6	75	131	22	30	59	<1	640
Trichlorotrifluoroethane	ND‡	-	-	-	-	-	-	-	-
1,1,1-Trichloroethane	39	28	72	1,575†	300	1,100	5,400	19	110,000
Trichloroethylene	41	21	51	469	100	360	1,100	2.2	1,300
Tetrachloroethylene	41	24	59	1,400	200	1,000	1,900	70	8,200
Total Chlorine	39	38	97	3,128§	1,780	7,790	13,100	88	181,000
Other Organics									
Benzo(a)pyrene	7	5	71	4	1.4	3.6	12	<1	12
PCBs	42	3	7	182	17	50	50	<1	500

* Mean was calculated for detected concentrations only.
† One sample with a very high concentration (110,000 ppm) was omitted to avoid distortion of the mean.
‡ No data were available for this constituent.
§ Two samples with very high concentrations (75,400 and 181,000 ppm) were omitted to avoid distortion of the mean.

Source: Appendix B contains the raw analytical data and references.

Table 42

SUMMARY OF CONTAMINANT LEVELS IN WASTEWATER GENERATED DURING WASTE OIL STORAGE AND PROCESSING

	Total analyzed samples	Samples with detected contaminant		Mean concentration* (ppm)	Median concentration (ppm)	Concentration at 75th percentile (ppm)	Concentration at 90th percentile (ppm)	Concentration range (ppm)	
		number	percent					Low	High
Metals									
Arsenic	16	10	63	3.4	0.10	0.68	22	0.03	22
Barium	19	12	63	80	1.0	29	241	0	300
Cadmium	19	7	37	0.34†	0.55	1.1	37	0	37
Chromium	17	8	47	10	1.04	8.8	68	0	68
Lead	19	15	79	271	5	107	585	<0.1	2,300
Zinc	19	17	89	250	5.5	200	1,300	<0.005	1,650
Chlorinated Solvents									
1,1,1-Trichloroethane	13	10	77	666	250	610	1,800	12	1,900
Trichloroethylene	11	7	64	561	100	910	2,600	20	2,600
Tetrachloroethylene	13	10	77	309	110	580	700	3.3	1,300
Total Chlorine	5	5	100	1,566	1,140	1,920	4,170	76	4,170
Other Organics									
Benzene	10	8	80	364	290	550	890	<0.4	890
Toluene	10	10	100	1,306	693	1,300	5,800	14	5,800
Benzo(a)anthracene	2	0	0	-	-	-	-	<0.02	<1
Benzo(a)pyrene	2	0	0	-	-	-	-	<0.02	<1
Naphthalene	8	6	75	283	229	470	700	0.7	700
PCBs	21	5	24	2.9	0.19	0.2	14	0.04	14

* Calculated for detected concentrations only.

† One sample with a very high concentration (37 ppm) was omitted to avoid distortion of the mean.

Source: Appendix B contains the raw analytical data and references.

the constituents in the water and oil phases. The metals remain in the oil rather than settle with the wastewater. The low median metals concentration in the wastewater is due to the small amount of oil which remains in the separated water fraction. The chlorinated and aromatic solvents show fairly high concentrations in the wastewater, but not significantly different from those found in the oil. Solubility of these contaminants is similar in both phases. One-fourth of the wastewater samples were found to contain PCBs. No PNAs were detected in wastewater, but the data were limited (only two samples were analyzed).

4.4.3 Spent Clays from Used Oil Processing

Clays are primarily used for lube oil polishing by re-refiners, but they find application as a used oil filtration media. Table 43 shows a summary of metals concentrations in spent clays. Metals content is lowest in spent clays used to polish lube oils from distillation/clay re-refining processes. The highest levels are reported for clay used in contact filtration processing and chemical treatment/clay bead re-refining. Intermediate levels have been measured in clays from acid/clay re-refining facilities.

Most spent clays have insignificant levels of chlorinated and aromatic solvents because these contaminants are separated from the used oil prior to contacting the clay. A possible exception is spent clay used in a contact filtration process (this is an uncommon practice). Higher molecular weight hydrocarbons such as PCBs and PNAs have not been measured, but their presence in spent clay is probable at levels directly related to their concentration in the used oil. Therefore, significant contamination by these constituents is possible.

Table 43

SUMMARY OF CONTAMINANT LEVELS IN SPENT CLAY USED IN WASTE OIL PROCESSING

	Total analyzed samples	Samples with detected contaminant		Mean concentration* (ppm)	Median concentration (ppm)	Concentration range (ppm)	
		number	percent			low	high
Metals							
Arsenic	7	6	86	8.4	3.7	<0.02	24
Barium	7	4	57	242	76	<1	628
Cadmium	7	7	100	6.9	11	0.5	13
Chromium	7	7	100	35	17	5	169
Lead	7	3	43	614	1	<1	1,200
Zinc	7	7	100	230	76	52	800

* Calculated for detected concentrations only.

Source: Appendix B contains the raw analytical data and references.

4.4.4 Distillation Bottoms from Re-Refining Facilities

Re-refiners who use distillation processes generate distillation bottoms which may be marketed as asphalt extenders or disposed of in some manner. Comparative data are available on metals concentrations in distillation bottoms (see Table 44). A single analysis was performed to measure PCBs and PNAs content; neither of these constituents was detected.

Table 44 summarizes the results of six metals analyses in distillation bottoms. The data indicate that fairly high levels of each metal are present. The distillation process concentrates the metals from the used oil into the bottoms material. Therefore, the metals content is directly related to levels in the used oil.

4.4.5 Other Used Oil Re-Refining and Processing Residues

In addition to the four major residues discussed in the preceding sections, re-refiners and reprocessors generate several other residues. Some residues for which limited analytical results have been obtained include:

- Tank bottoms from storage/settling tanks
- Solvent sludges from re-refining
- Acid sludge from re-refining
- Ultrafiltrate solids
- Centrifuge sludge
- Activated carbon from re-refining (PROP)*
- Filter cake from re-refining (PROP)
- Filter sludge from screen filtration

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* Phillips Re-refined Oil Process developed by Phillips Petroleum Company in Bartlesville, Oklahoma.

Table 44

SUMMARY OF CONTAMINANT LEVELS IN DISTILLATION BOTTOMS FROM RE-REFINING FACILITIES

	Total samples analyzed	Samples with detected contaminant		Mean concentration* (ppm)	Median concentration (ppm)	Concentration range (ppm)	
		number	percent			low	high
Metals							
Arsenic	4	3	75	8.1	1	<0.01	15
Barium	5	5	100	477	25	6	1,400
Cadmium	5	4	80	12.7	9	0	29
Chromium	5	5	100	43.2	35	7	100
Lead	5	5	100	6,543	4,235	1,090	15,000
Zinc	5	5	100	1,360.8	133	85	3,500

* Calculated for detected concentrations only.

Source: Appendix B contains the raw analytical data and references.

A complete presentation of analytical results for these residues can be found in Appendix B. All of these materials are contaminated by heavy metals. Lead concentrations are particularly high, with concentrations above 10,000 ppm common for some of the re-refining sludges and filter cakes. The simple screen filtration processes are not efficient methods to remove metals from used oil, so those sludges have the lowest metal concentrations of these residues. Nevertheless, lead levels in screen filtration sludges have been measured at 100 ppm.

Little or no data are available on contamination of these residues by hazardous constituents other than heavy metals. Such contamination is probably directly related to the contamination of the used oil which is processed.

Section 5

USED OIL MARKETING AND DISPOSAL

5.1 OVERVIEW

Used oil which is handled by the management system described in Section 4 is sold by collectors, processors, and re-refiners for several end-uses. Burning is clearly the major end-use market. Road oiling and re-refined lube base stock are smaller markets but still significant. Other minor markets exist such as asphalt extenders, flotation oils, and form oils. Very little collected oil is disposed of; however, losses do occur in residues and as a result of spills and leaks. This section examines the end-uses for used oil with respect to quantities and composition. The levels of contaminants in used oil burned as fuel are compared to the levels in virgin oil products.

5.2 SUMMARY OF USED OIL END-USE MARKETS

Table 45 shows end-use and disposal estimates for all generated used oil. The data are broken down according to whether the oil entered the used oil management system or not. The oil which does not flow into the management system is reused or disposed of by the generator.

About 73 percent of the oil which flows through the management system is believed to be burned as fuel compared to only 19 percent of that which never enters the system. Also, about 9 percent of the system oil is re-refined to new lube oil and 5 percent is used for non-fuel industrial applications such as flotation oils and asphalt extenders. About two-thirds of the oil not entering the management system is lost through disposal--

TABLE 45. END-USES FOR USED OIL, 1983‡

End-use or disposal	Used Oil Flowing Through Management System (10^6 gal)	Used Oil Flowing Through Management System (percent)‡	Used Oil Not Entering Management System* (10^6 gal)	Used Oil Not Entering Management System* (percent)‡	Total Generated Used Oil (10^6 gal)	Total Generated Used Oil (percent)‡
Re-refined Lube Oil or On-Site Recycling	62.7	9.4	44**	8.2	106.7	8.8
Non-Fuel Industrial†	34.9	5.2	0	0	34.9	2.9
Burning						
Large Boilers Small Boilers	454.0	67.9	8.0‡‡	1.5	462.0	38.3
Cement Kilns	5.0	0.7	0	0	5.0	0.4
Diesel Engines	0	0	15.0	2.8	15.0	1.2
Space Heaters	0	0	34.2	6.4	34.2	2.8
On-Site Boilers	30.8	4.6	43.1	8.0	73.9	6.1
Subtotal - Burning	489.8	73.2	100.3‡‡	18.7	590.1	48.9
Road Oiling	39.6	5.9	28.9	5.4	68.5	5.7
Disposal						
Landfill Incineration	42.1	6.3	122.6	22.8	164.7	13.7
Dumping	0	0	241.2	44.9	241.2	20.0
Subtotal - Disposal	42.1	6.3	363.8	67.7	405.9	33.7
Grand Total	669.1	100	537.0	100	1,206.1	100

* Includes used oil which is managed entirely by the generator either through reuse or disposal.

† Includes flotation oils in phosphate industry and asphalt extenders.

‡ All volumes represent oil with consumed additives. Solid and liquid contaminants (including water) are not included in quantities.

** Reuse of lubricants by industry may use sophisticated re-refining technologies or simpler processor technologies.

‡‡ These 8 million gallons were burned by DIYers in various ways, but primarily blended with home heating oil.

Source: See Appendix C for oil flow description methodology.

including widespread dumping. About one-half of all dumping is by DIYers, and the other half is by large off-road vehicle operators such as farmers, miners, and construction workers.

Of the total generated oil nearly half is burned for energy recovery. Only about 5.2 percent becomes new re-refined lube oil, somewhat less than the amount used as a road oil (8.8 percent is reused if onsite industrial processing is included).

5.3 BURNING USED OIL AS FUEL

Nearly 600 million gallons of used oil were burned primarily as fuel in 1983 in the United States. This is the single largest end-use category comprising about 73 percent of all of the used oil which enters the management system and almost half of all generated used oil. Used oil is burned in various boiler types and sizes, small oil space heaters, incinerators, asphalt plants, cement kilns, and diesel engines. Any facility designed to burn No. 6 fuel oil and most facilities designed to burn No. 4 and No. 5 fuel oils can burn straight used oil. Some modifications may be necessary in systems designed to burn the lighter fuels (4). Blended fuel oil products which typically contain 5 to 20 percent used oil can be burned in virtually any boiler type if the virgin fuel fraction is No. 3 fuel oil or lighter. Blending with No. 3 oil and burning in small and medium- size residential and commercial boilers is common in some locations, particularly the northeast.

Most used oil which is burned has been processed to some degree by minor or major processing technologies (see Section 4 descriptions and Section 2 definitions). In some cases, the burners of the oil carry out some processing of their own. For example, a correctional center in Carson

City, Nevada purchases unprocessed oil which they heat treat and centrifuge to remove water, sludge, and up to 80 percent of the lead in the oil (9). This in-house processing by relatively large users insures consistent oil quality and keeps the purchase price down. Of course, in-house processing can only be carried out with appropriate technical staff to monitor these practices.

The environmental impacts of burning used oil depend on:

(1) Concentration of hazardous contaminants in the oil

(2) Burner design

(3) Emissions control equipment

(4) Stack height

(5) Meteorological conditions

(6) Number of emitting sources within an area

This section provides a summary of the concentration of hazardous constituents in the oil (factor 1 above). A recently completed report for the U.S. EPA examined the other factors regarding the risks associated with burning used oil (4).

Table 46 summarizes the composition data for about 350 samples identified as used oil which was to be burned as fuel. It is important to emphasize that hundreds of other used oil samples were analyzed for which end-use was not known. Most of these samples were probably taken from batches of used oil which were also burned since burning is such an important end-use market. Therefore, although the sample size is large for the data presentation in Table 46, one should be aware of the fact

Table 46

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN USED OIL BURNED AS FUEL

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	223	46	20	19.5	5	5	19	0.9	94
Barium	282	238	84	136.9	50	140	240	0	1,710
Cadmium	264	92	34	4.0	7	10	10	<0.2	40
Chromium	214	168	78	37.7	5.3	11	60	0	571
Lead	348	321	92	554.7	390	821	1,080	0	4,730
Zinc	253	250	98	706.9	628	831	1,080	<5	8,610
Chlorinated Solvents									
Dichlorodifluoromethane	74	51	68	373.3	30	210	860	<1	2,200
Trichlorotrifluoroethane	10	8	80	953.8	620	940	1,400	<20	1,900
1,1,1-Trichloroethane	308	232	75	1,598.2	420	1,400	3,100	<2	1,500
Trichloroethylene	305	181	59	850.1	150	370	830	<1	4,000
Tetrachloroethylene	300	225	75	1,209.8	200	780	1,700	<1	3,200
Total Chlorine	252	249	98	5,540	2,300	4,900	9,500	<100	459,000
Other Organics									
Benzene	72	47	65	1,715.8	100	200	360	<3	55,000
Toluene	75	70	93	3,353.1	890	2,900	7,400	<3	55,000
Xylenes	72	68	94	3,519.5	820	1,900	3,400	<5	57,000
Benzo(a)anthracene	11	9	81	24	12	25	30	<5	60
Benzo(a)pyrene	31	21	67	9.5	5	12	14	<1	17
Naphthalene	11	11	100	588.2	420	750	990	210	1,400
PCBs	321	38	11	167.2	6	30	50	0	3,150

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

that any used oil could actually be burned. It is recommended that Table 2 in Section 1 which summarizes the contamination of all 1,071 samples also be reviewed.

The data in Table 46 show that burned used oil can contain high levels of many hazardous constituents.

The composition of virgin fuel oils is important as a point of comparison to used oil. Generally, used oils take the place of heavy fuel oils (e.g., residual oils); however, they may be blended with lighter fuels (e.g., distillate oils).

As with all crude and refined products, the hydrocarbon composition in fuel oils varies depending upon the source of crude oil and the specific refining process utilized. Table 47 shows the variations which commonly occur in hydrocarbon composition for several middle distillates which include kerosene, diesel fuel, and No. 1 and No. 2 fuel oils. These data show that the saturated hydrocarbons* generally comprise a larger fraction of these fuels than aromatics and unsaturates. However, the aromatics and unsaturates together comprise 10 to 65 percent of these products by weight. These levels are important because a subset of this group is polynuclear aromatics (PNA's), some of which are proven carcinogens.

The heavier fuel oils (Numbers 3 to 6) contain hydrocarbons of higher molecular weight and generally higher levels of aromatics and unsaturates than the light and middle distillates.

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* Saturated hydrocarbons contain no carbon-carbon double bonds and include primarily alkanes and cycloalkanes.

TABLE 47. VARIATION IN HYDROCARBON COMPOSITION OF MIDDLE DISTILLATES

Hydrocarbon	Range (in wt. %)	Reported values (in wt. %) a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
Saturated paraffins	34.6-90	37-43	34.6	60	35	25	-	74	71-76	75	60	78.9	72.8	72.6	77	50	80.4
Cycloparaffins		26-32		30	55	50	65						14				
Aromatics	10-58	30-32	57.5	10	15	25	33	26	24-29	25	40	19.5	58	27	23	50	19.6
Unsaturates	0-75	-	7.5	-	-	-	2	-	-	-	-	1.6	5.2	0.4	-	-	-

a = Fuel oil No. 2; b = Cracked middle distillate; c = Paraffin-base kerosene; d = Paraffin-base middle distillate; e = Aromatic-base kerosene; f = Aromatic-base middle distillate; g = Diesel fuel; h = Middle distillate; i = Straight-run diesel fuel; j = Middle distillate; k = Diesel fuel; l = Fuel oil No. 2; m = Diesel fuel; n = Straight-run middle distillate; o = Cracked middle distillate; p = Middle distillate.

Source: (19).

Table 48 summarizes typical concentration ranges for several hazardous constituents and total chlorine in virgin fuel oils. Some general observations can be drawn from the typical ranges and from the raw analytical results. As the fuel oils become heavier, contamination by heavy metals, PNA's*, and total chlorine increases. No. 2 distillate fuel contains virtually no detectable metals, except perhaps very low lead levels. Total chlorine is generally below 5 ppm and the combined concentration of benzo(a)anthracene and benzo(a)pyrene is typically less than 1.0 ppm. In the heavier fuels, the concentrations of barium, lead, and chromium typically range from 2 to 5 ppm. The highest reported lead concentration was 10 ppm in a No. 4 fuel oil. Barium was reported up to 13 ppm and chromium up to 14 ppm in No. 4 and residual fuels, respectively. Total chlorine is typically below 10 ppm in the heavier fuels; however, concentrations between 30 and 85 ppm have been reported by the National Bureau of Standards. The combined concentrations of benzo(a)anthracene and benzo(a)pyrene are usually below 3 ppm for No. 3 and No. 4 fuel oil, but can be much higher for residual fuels (over 100 ppm).

The contamination of used and unused oils with potentially hazardous constituents is compared in Tables 49 and 50. Table 49 distinguishes concentration levels for specific fuel oils while Table 50 combines the virgin fuel oil summary into a single group.

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* Polynuclear aromatics.

TABLE 48. TYPICAL CONCENTRATION RANGES FOR SEVERAL POTENTIALLY HAZARDOUS CONSTITUENTS IN VIRGIN FUEL OILS

	No. 2 distillate (ppm)	No. 3 and 4 fuel oils (ppm)	Residual fuels (ppm)
Metals			
Arsenic	ND*	ND-0.058	0.06-0.8
Barium	ND	ND-13	0.3-5.0
Cadmium	ND	ND	ND-1.0
Chromium	ND	ND-0.09	0.11-14
Lead	ND-5.0	ND-10	1.0-4.1
Zinc	-	0.06-0.32	ND-2.0
Total chlorine	0.03-5.0	5.7-7.8	0.2-85
Benzo(a)anthracene	0.001-0.471	0.02-2.82	18-97
Benzo(a)pyrene	0.001-0.60	0.57-2.1	2.9-44

* ND: Not detectable.

Source: (23-29, 30, 39, 40).

TABLE 49. COMPARISON OF HEAVY METALS CONCENTRATION IN USED AND SPECIFIC VIRGIN FUEL OILS*

Contaminant	Used Oil			No. 2 Distillate			No. 3 and 4 Fuel Oils			No. 6 and Residual Fuel Oils		
	Percent detection	Median concentration (ppm)	90th percentile (ppm)	Percent detection	Median concentration (ppm)	95th percentile (ppm)	Percent detection	Median concentration (ppm)	95th percentile (ppm)	Percent detection	Median concentration (ppm)	95th percentile (ppm)
Arsenic	25	ND†	18	33	ND	3.1	43	ND	4.5	82	2	4.9
Cadmium	36	3	10	0	ND	ND	8	ND	4.95	17	ND	1.0
Chromium	78	6.5	35	0	ND	ND	46	ND	0.35	38	1.5	14
Lead	91	240	1,200	38	ND	5.0	67	2.2	11	60	2.1	10.5

* Undetected concentrations were assumed to be equal to detection levels to determine median and percentile concentrations. Therefore, the median may be greater than zero even though less than 50 percent of the samples showed measurable levels of the contaminant.

† ND - Indicates not detected.

Source: Appendix A for used oil and References 21, 23-28, 39, 40, 44.

TABLE 50. COMPARISON OF HEAVY METALS IN USED OILS AND VIRGIN FUEL OIL*

	Used Oil				Virgin Fuel Oils†			
Contaminant	Number of samples	Percent detection	Median concentration (ppm)	90th percentile (ppm)	Number of samples	Percent detection	Median concentration (ppm)	95th percentile (ppm)
Arsenic	537	25	ND‡	18	45	60	2	4.9
Cadmium	744	36	3	10	44	11	ND	1.3
Chromium	756	78	6.5	35	46	35	1.0	13
Lead	835	91	240	1,200	50	56	2	11

* Undetected concentrations were assumed to be equal to detection levels to determine median and percentile concentrations. Therefore, the median may be greater than zero even though less than 50 percent of the samples showed measurable levels of the contaminant.

† Includes data for all types of distillate fuel oils and residual oils.

‡ ND - Indicates not detected.

Source: Appendix A data for used oil and References 21, 23-28, 39, and 40 for virgin fuel oils.

The comparative results in Tables 49 and 50 show that the levels of most hazardous constituents are typically much higher in used oils than in unused oils. All metals have been detected in fuel oils, but at relatively low levels compared to used oil concentrations. Chromium, arsenic, and cadmium have been detected in some heavy fuel oils at levels which sometimes approach the levels in used oil.

Chlorinated solvents generally are not found in unused oils, whereas typical levels of 200 to 2,000 ppm are common in used oils. Total chlorine concentrations of 5 to 10 ppm are common in fuel oils compared to typical levels above 1,000 ppm in used oils. Chlorine is primarily a constituent of organic compounds (usually solvents) in used oils and in inorganic form (primarily salts) in unused oils. Benzo(a)pyrene and benzo(a)-anthracene concentrations in heavy residual oils can be as high or higher than typical concentrations in used oils. Lower concentrations of these PNAs were measured in the distillate fuels.

No PCBs have been found in any unused fuel oils whereas one-third of the used oil samples contained measurable levels of this group of constituents.

5.3.1 Used Oil Blending

A major fraction of the used oil which is burned is blended with virgin oils (No. 3, 4, 5, and 6 and diesel fuel). The details of blending practices including quantities, blending ratios, fuel types, and end-use markets are not available. Most blending takes place at virgin fuel oil dealers which are for the purposes of this study, outside the used oil management system. Virgin fuel oil dealers are end-use markets for the collectors and processors. In many cases the collectors and processors who sell product oil to dealers do not know where the oil is ultimately burned. This type of information is generally difficult to obtain from dealers who blend. A smaller fraction of blending occurs within the management system by major processors. Most of the information on blending practices was obtained from those processors who blend on-site.

The criteria used for oil blending varies greatly. Some blenders mix waste oil and virgin oil according to a standard blending ratio (i.e., 9 parts virgin oil with 1 part waste oil), while others blend to a desired viscosity, moisture content or any of a number of other factors. The criteria utilized are a function of the product specifications or characteristics which the blender or his customer have established.

Blending criteria which are common include:

- constant blending ratio
- viscosity
- heat content
- percent solids
- percent moisture
- customer fuel specification

Except in cases where a constant blending ratio is applied, some analysis of the waste oil is necessary. For this reason, most blenders have receiving tanks designated for storage of waste oil. After a determination of the proper blending ratio to achieve the desired product quality is made, the waste oil is metered into a blending tank, where it is mixed with the appropriate volume of virgin oil. Most blenders use pumps to transfer waste oil to the blending vessel; only a few use gravity flow. Mixing is accomplished in a number of ways, including mechanical mixing, aeration, and in-line mixing. The type of mixing employed depends on the relative viscosities of the virgin and waste oils, and on the volume of oil which is blended. Some blenders transfer the blended oil to a storage tank, while others transfer the oil directly to a transport vehicle for delivery to the customer.

Blending improves oil quality by diluting the concentration of contaminants, both hazardous and non-hazardous. In some cases, a high blending ratio may decrease the concentration of hazardous constituents from unacceptable to acceptable levels. Table 51 summarizes the concentration of hazardous constituents in used oil blended with virgin fuel oil at a blending ratio of 9 parts virgin fuel to one part used oil. These data show that even with blending fairly high concentrations of some contaminants can remain.

5.4 ROAD OILING WITH USED OIL

In 1982, the U.S. EPA commissioned a study to carry out a state-by-state survey to evaluate road oiling practices (7). The quantity of the available data for the states varied considerably. Some states maintain used oil programs which attempt to monitor oil generation, recovery, and reuse. These states often have a fairly good idea of the amount of road oiling which occurs. However, the existence of a used oil recycling program by no means assures the availability of quantitative data on used oil usage. Other states have no programs but road oiling practices can still be estimated based upon conversations with state environmental agency personnel and local used oil collectors.

Table 51

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN USED OIL BLENDED WITH VIRGIN FUEL OIL BURNED AS FUEL ‡

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	223	46	20	3.8	2.3	2.3	3.7	<1.9	11.[illegible]
Barium	282	238	84	13.7	5.0	14.0	24.0	0	171.0
Cadmium	264	92	34	0.4	0.7	1.0	1.0	<0.02	4.0
Chromium	214	168	78	4.7	1.4	2.0	6.9	0.9	58.0
Lead	348	321	92	57.3	40.8	83.9	109.8	1.8	474.8
Zinc	253	250	98	70.7	62.8	83.1	108.0	<0.5	861.0
Chlorinated Solvents									
Dichlorodifluoromethane	74	51	68	37.3	3.0	21.0	86.0	<0.1	220.0
Trichlorotrifluoroethane	10	8	80	95.4	62.0	94.0	140.0	<2.0	190.0
1,1,1-Trichloroethane	308	232	75	159.8	42.0	140.0	310.0	<0.2	150.0
Trichloroethylene	305	181	59	85.0	15.0	37.0	83.0	<0.1	400.0
Tetrachloroethylene	300	225	75	121.0	20.0	78.0	170.0	<0.1	320.0
Total Chlorine	252	249	98	554.0	230.0	490.0	1,800.0	<10.0	45,900.0
Other Organics									
Benzene	72	47	65	171.6	10.0	20.0	36.0	<0.3	5,500.0
Toluene	75	70	93	335.3	89.0	290.0	740.0	<0.3	5,500.0
Xylenes	72	68	94	352.0	82.0	190.0	340.0	<0.5	5,700.0
Benzo(a)anthracene	11	9	81	2.4	1.2	2.5	3.0	<0.5	6.0
Benzo(a)pyrene	31	21	67	1.0	0.5	1.2	1.4	<0.1	1.7
Naphthalene	11	11	100	58.8	42.0	75.0	99.0	21.0	140.0
PCBs	321	38	11	16.7	0.6	3.0	5.0	0	315.0

* Calculated for detected concentrations only.
† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).
‡ Blending ratio equals 9 parts virgin oil per part of used oil.

Source: Appendix A data.

As a result of this survey, it was estimated that about 40 to 60 million gallons of used oil were used as commercially applied road oils in 1982 in the United States. An additional 20 to 40 million gallons was applied by generators including farmers, mining and construction companies, and other miscellaneous industries (7). These estimates agree fairly well with independent estimates developed on a facility basis for this study. The total estimate of 68.5 million gallons in 1983 used for this study is at the low end of the range for 1982 as would be expected since activity is decreasing. In 1982, the largest gallonage was used in California, which accounted for about one-fifth of the national total. Recent state regulatory action (1983) may change California's status as the number one road oiling state. Other states in which large amounts were used include Ohio, Arizona, Iowa, Wisconsin, Washington, Georgia, and Colorado. Overall, the commercial use of used oil on roads is only about 3 percent of the total amount of used oil generated, and about 6 percent of all collected oil. These numbers indicate that from a nationwide perspective it is not a major disposal (or recycle) mechanism for used oil. However, from a local or even regional perspective, it may be a major market for used oil. Figure 10 shows the extent of commercial road oiling by state. Four main areas of road oiling were identified and two areas of lower activity are noteworthy. Most road oiling takes place in the northern Rocky Mountain states, the extreme southwest, the southeast, and in a cluster of states along the Ohio River. Moderate levels of road oiling can be found in the northwest and in northern New England.

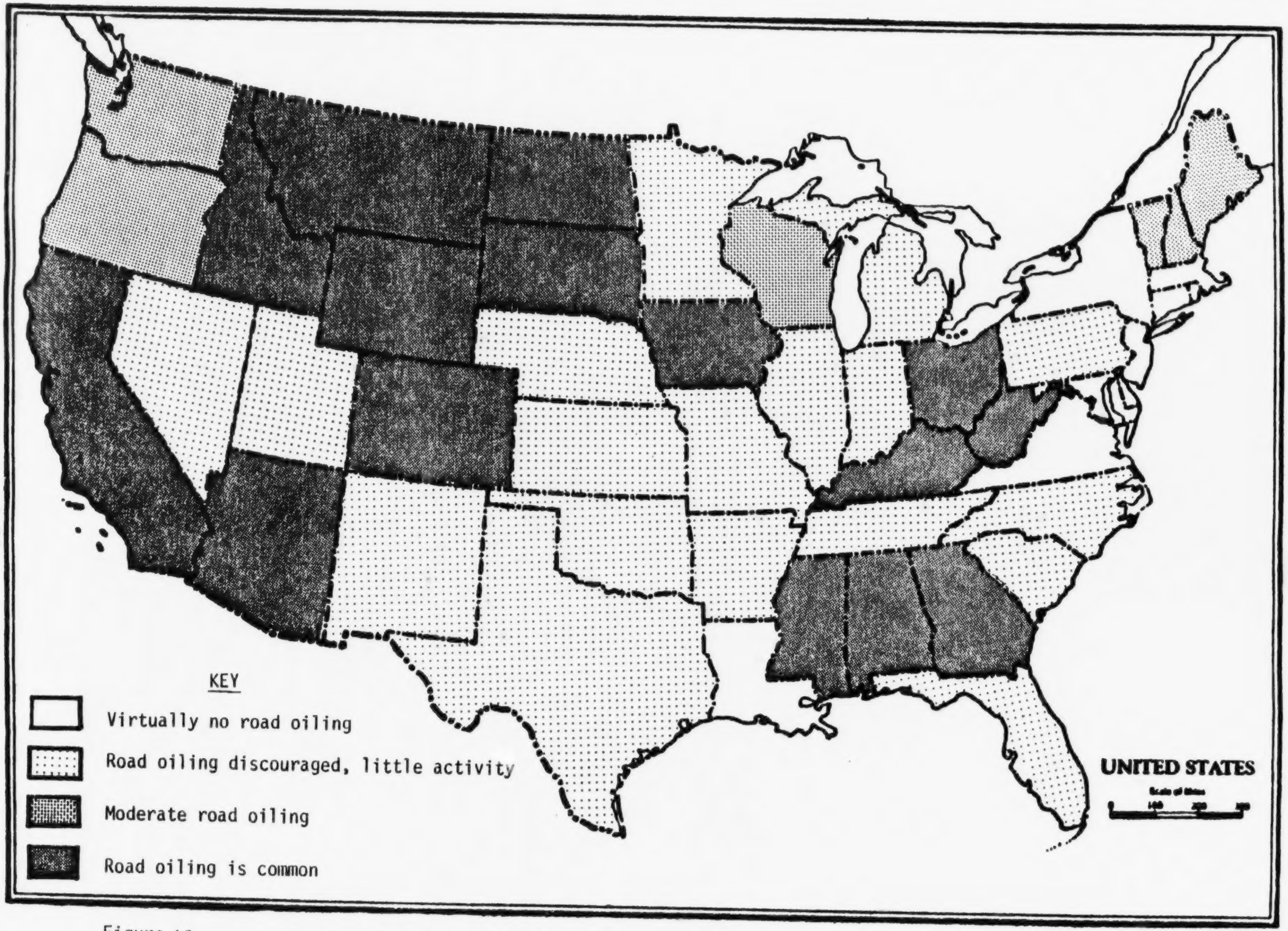
KEY
Virtually no road oiling
Road oiling discouraged, little activity
Moderate road oiling
Road oiling is common
UNITED STATES
Scale of Miles

Figure 10. Extent of road oiling in the United States - 1982.
Source: (7).

Road oil is typically applied at a rate of about 0.25 gallons per square yard. The material which is applied is not strictly used oil, although unprocessed oil (as collected) is probably the most common material used. Often a road oiler will use the bottom layers of settled used oil for road oiling. Depending on the collected oil composition, this bottom layer material is likely to have a high bottom sediment and water (BS&W) content. Some used oil processors will sell the top layers of settled oil as fuel and the bottom layers as road oil. However, the solids content of road oil must be controlled to some degree because of potential problems with clogging the orifices on the application apparatus.

The environmental impacts of road oiling with used oil are dependent on many factors including the presence of hazardous constituents in the oil (see References 7 and 8 for a detailed environmental impact assessment). Table 52 summarizes the measured concentration of hazardous constituents in about 230 road oil samples. Although the data show that road oils contain high levels of many hazardous constituents, the overall concentrations of hazardous metals in road oils are lower than those measured in oils which are burned (see Table 46). On the other hand, the concentration of chlorinated solvents seem somewhat higher in the road oil samples. One possible reason for this result is the common use of bottom layers from storage tanks for road oiling. If a tank is drained from the bottom for road oiling, a fairly high water content could be present. Since this water layer usually contains relatively low levels of metals and equal or greater concentrations of the more water-soluble solvents compared to straight oil layers, road oils may exhibit these characteristics with respect to used oils burned as fuel. Nevertheless, since virtually any used oil may be used as a road oil, the probability of contamination remains high.

Table 52

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN WASTE OIL USED AS ROAD OIL

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	75	45	59	21.06	8	19	27	<5	94
Barium	90	83	92	87.27	30	50	160	<2.5	1,070
Cadmium	149	8	5	1.31	10	10	10	<0.2	10
Chromium	166	108	65	34.51	10	14	60	<1	431
Lead	166	155	93	403.37	267	443	856	<5	3,250
Zinc	161	156	96	492.47	380	720	990	<1	2,670
Chlorinated Solvents									
Dichlorodifluoromethane	17	16	94	136.06	10	150	210	<1	640
Trichlorotrifluoroethane	2	2	100	330,000	110,000	110,000	110,000	110,000	550,000
1,1,1-Trichloroethane	93	64	68	4,279.82	200	1,100	2,700	<3	110,000
Trichloroethylene	89	38	42	1,736.76	100	200	730	<1	40,000
Tetrachloroethylene	82	49	59	2,241.63	130	830	1,700	<1	32,000
Total Chlorine	72	68	94	5,500	2,000	6,100	10,600	<100	49,400
Other Organics									
Benzene	6	3	50	124	15	17	18	<10	340
Toluene	6	6	100	685	140	190	580	17	3,100
Xylenes	8	8	100	26,578.87	160	2,900	70,000	75	139,000
Benzo(a)anthracene	2	2	100	510	360	360	360	360	660
Benzo(a)pyrene	2	2	100	267.5	130	130	130	130	405
Naphthalene				NOT MEASURED					
PCBs	227	78	34	23.14	10	20	50	<0.4	225

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

5.5 RE-REFINING USED OIL

Re-refining is a type of processing rather than an end-use application. It is an intermediate step associated with the ultimate reuse of used oil as a lube base stock. Little data are available on the presence of hazardous constituents in re-refined base stock, but it is generally free of the 20 constituents which have been summarized throughout this report. There have been undocumented reports from re-refiners that some re-refined lubes have contained PCBs and polynuclear aromatics (PNAs) such as benzo(a)pyrene. Also, industry representatives have indicated that re-refined lube oils from acid-clay processes sometimes fail to thoroughly remove the metals associated with additive packages (primarily zinc and barium). The limited data which are available do not support these hypotheses because these particular contaminants and circumstances have not been assessed.

Some volatile hazardous constituents found in used oil including the chlorinated and aromatic solvents end up in a light distillate oil fraction generated in re-refining processes. High concentrations of several solvents have been measured in this fuel product which is often burned on-site to supply process heat requirements, but it may be marketed to off-site burners, as well.

In vacuum distillation re-refineries (the most common and growing technology in 1983), the heavy metal contaminants concentrate in the distillation bottoms which are landfilled or sold as asphalt extenders.

Because re-refiner's product oil (lube base stock) is subject to stringent quality standards, re-refiners are generally more concerned about the quality of incoming feedstock than processors, particularly the presence of PCBs and PNAs which may not be removed during re-refining. Table 53 summarizes the concentration of several hazardous constituents in used oil delivered to re-refineries. Overall, there appears to be little difference in the quality of oil delivered to re-refiners as that which is burned as fuel. This indicates that both markets probably compete for the same oil.

5.6 MISCELLANEOUS END-USE MARKETS

In addition to the three major end-use markets for used oil described above (burning, road oiling, and re-refining), a few minor reuse practices have been identified. The phosphate industry uses used oil as a flotation oil in their processes. This is a fairly significant market in some southern states, particularly Florida. Asphalt plants sometimes blend used oils into their product as an extender as well as burning used oil as a major fuel source. A third important commercial end-use market is form oil for concrete construction. This is a minor practice primarily due to the inconvenience of obtaining and spraying forms with used oil, the small quantities used on a construction site, and the availability of other oils, such as diesel, which are already on-site.

Other noncommercial reuse practices have been identified. Generators report using used oils as machinery lubricants, pesticide carriers, weed killers, cattle oilers; and even as an all-purpose cleaner.

No data are available on the presence of hazardous constituents in used oil consumed for the minor end-use applications discussed in this section. It should be assumed that any used oil could potentially be used for these purposes. Table 2 summarizes the presence of hazardous constituents in all used oil samples.

Table 53

CONCENTRATION OF POTENTIALLY HAZARDOUS CONSTITUENTS IN USED OIL DELIVERED TO REFINERIES

	Total samples analyzed	Samples with detected contaminants		Mean concentration * (ppm)	Median concentration † (ppm)	Concentration at 75th percentile † (ppm)	Concentration at 90th percentile † (ppm)	Concentration range (ppm)	
		number	percent					low	high
Metals									
Arsenic	61	14	22	15.35	5	5	13	<5	33
Barium	104	87	83	161.43	40	190	360	0	1,631
Cadmium	77	11	14	2.57	5	10	10	0	10
Chromium	90	70	77	23.69	8	13	26	<0.5	431
Lead	94	85	90	681.15	58	700	2,000	<1	11,000
Zinc	106	105	99	458.03	330	660	980	<1	5,000
Chlorinated Solvents									
Dichlorodifluoromethane				NOT MEASURED					
Trichlorotrifluoromethane				NOT MEASURED					
1,1,1-Trichloroethane	54	33	61	2,556.06	300	1,100	4,400	<7	30,000
Trichloroethylene	54	6	11	5,657.66	100	100	100	<7	26,000
Tetrachloroethylene	54	25	46	1,729.19	100	400	900	<7	20,000
Total Chlorine	75	74	98	5,300	1,800	6,200	11,000	<100	49,400
Other Organics									
Benzene	13	4	30	380.5	15	16	76	<7	820
Toluene	13	9	69	2,418.33	120	330	4,000	<10	12,000
Xylenes	13	8	61	5,057.5	150	850	1,400	<7	28,000
Benzo(a)anthracene				NOT MEASURED					
Benzo(a)pyrene	10	10	100	12.88	12	13	14	8.8	16
Naphthalene				NOT MEASURED					
PCBs	53	5	9	31	10	50	50	<1	100

* Calculated for detected concentrations only.

† To determine median and percentile concentrations, nondetected concentrations were assumed to be equal to the detection level (e.g., <5 = 5).

Source: Appendix A data.

5.7 USED OIL DISPOSAL

Used oil disposal includes conventional accepted disposal techniques such as landfilling and incineration as well as uncontrolled dumping. In each case, the oil is lost with respect to further reuse or recycling.

Only very low quality oils are disposed of by generators and collectors primarily because virtually all used oils have value. (In some cases, disposal of good quality oil takes place because the quantity is not large enough to warrant storage and sale to a collector.) Processors and re-refiners will generally accept oils with BS&W contents up to 50 percent; however, the price paid is very low (perhaps no price is paid) for poor quality oil. Disposal is a costly alternative which may be subject to various state and federal regulations. Thus, oils which are accumulated by generators seldom flow directly to disposal. It was estimated that about six percent of the generated oil flowed directly to disposal in 1983 (64.7 million gallons). This does not include oil which is generated by DIYers. Over 40 million gallons of relatively good quality DIYer oil is disposed of with municipal solid waste (5).

Collectors, processors, and re-refiners do dispose of used oil which is present in residues such as in-line filter residue, centrifuge solids, filter screen solids, tank bottoms, distillation bottoms, spent clay, and other settled sludges. These materials can contain appreciable quantities of oil and in total, about five percent of the used oil collected and processed is lost in this way. Most is believed to be landfilled, but some industry representatives report incineration as a practiced disposal method.

Large quantities of generated used oil are dumped (about 241 million gallons in 1983). Most of this oil is automotive engine oils. DIYers are believed to dump over 100 million gallons each year in backyards, down drains, along roadsides, and in miscellaneous other places. Most of the remainder is dumped by operators of large off-road equipment such as farmers, construction crews, mining companies, and the military.

Since most of the dumped oil is automotive engine oil, the data presented in Section 3 - Table 15 on automotive oils is relevant to this category. The disposed oil is basically processing residues which were described in Section 4 - Tables 41 to 44.

In addition to the disposal of "generated" used oil, considerable quantities which are not technically generated are also disposed of. "Not generated" means the oil is lost as part of its use. For example, oil which has dripped from machinery may be wiped from the floor with paper or cloth wipes which are disposed of with general plant solid waste. No attempt was made in this study to account for these types of losses and disposal practices.

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